VULNERABILITY OF WATER SYSTEMS

A study of the vulnerability of water systems
to radioactive fallout and methods
of increasing their survivability.

prepared for

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GUY B. PANERO INC.
468 Park Avenue South
New York, N. Y. 10016

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FOREWORD

This report summarizes studies made by the Research Division of Guy B. Panero Inc. to determine the vulnerability of water systems to radioactive fallout and the methods by which their survivability could be increased. The study concentrates upon the significance of residual radiation effects upon the system rather than upon the direct weapon effects (blast overpressure, thermal and initial radiation). There are two basic reasons for this approach:

1. The state of the art regarding interaction of direct weapons effects upon physical structures is quite advanced, whereas there are many areas where the effects of fallout on water systems could be more fully developed.

2. The affected area of radioactive contamination far exceeds that of significant blast overpressure damage.

Because of the immensity of the problem and its many ramifications, the keynote of this report is breadth rather than depth. Effort is applied here to identify the problems and their relative significance, and to indicate the areas needing further investigation and the possible approaches to them.

The study group wishes to thank the many people who contributed information and assistance, and in particular:

Mr. John F. Devaney	-	**Head, Systems Evaluation Division - Office of Civil Defense**
Mr. Robert C. Whitney	-	**Project Coordinator, Office of Civil Defense**
Mr. Peter C. Karalekas	-	**Chief Water Engineer, Springfield, Mass.**
Mr. Richard F. Shepardson	-	**Director, Springfield Civil Defense Agency**

Albert J. Marinello
Director of Research
Guy B. Panero Inc.

ABSTRACT

This report investigates the vulnerability of water supply systems to contamination by fallout and discusses various means of protecting them as well as alternate emergency operating procedures. The effect of numerous physical parameters and the significance of certain attributes of system components are studied. Alternate sources of potable water are reviewed and estimates made of their potential quantities. The results of this phase are compared with a spot check made on an arbitrarily selected city.

A comparison is also made of Civil Defense procedures of vital facilities in order to determine preferred methods of protection, and the relationship and application of these methods to water supply systems.

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SECTION 1

INTRODUCTION

1.1 SCOPE

Human survival after a nuclear attack is predicated to a great degree on the availability of potable water, not only during the shelter phase, but even more important, during the much longer post-shelter recovery phase.

Whether this water will be available or not depends upon the state of our advance planning and preparedness, and our resourcefulness in adjusting to the post-attack situation.

This report considers some of the effects that fallout radiation can have on the ability of existing water systems and supplies in the United States to satisfy the demands that will be placed upon them. Emphasis is given to the relationship and relative seriousness of this indirect weapons effect to various water system components, both in the planning and operating phases. Important areas of the problem that need study will be described, and possible measures to improve the survivability of the system against fallout radiation will be developed.

1.2 OBJECTIVES

Specific objectives of this study include:

a. Review current existing literature regarding fallout radiation effects and preferred methods of protection of vital facilities in order to define the problems and their relative significance to the protection of water systems.

b. Identify the basic water systems as to their various components, and to evaluate the effects that fallout can have on each of them during both the shelter phase and the post-shelter phase.

c. Identify procedures for the determination of the vulnerability of existing water systems, and demonstrate the application of these procedures to a specific community.

d. Investigate the alternate sources of potable water during the shelter phase and post-shelter phase.

SECTION 2

THE EFFECTS OF WEAPONS

2.1 GENERAL

The hypothecation of the extent of a nuclear attack and the ensuing degree of damage or radioactive activity is probably the most difficult phase of civil defense planning. The possible targets, number and yield of weapons, prevailing winds and numerous other parameters contribute great uncertainties to any such estimates; and must necessarily incur specific qualifications and limitations.

2.2 FALLOUT RADIATION

By definition, this report emphasizes the effects of fallout radiation to the exclusion of such direct effects of nuclear detonations as blast overpressure, thermal radiation and initial radiation. The value of such a qualification can be demonstrated by reference to Figure 2.1. This illustration shows, for various surface detonated weapons, the outside two-week dose directly downwind from one such blast. Noted on the curves are the limits of 0.5 psi overpressure, which is the approximate limit of minor and easily reparable damage to above ground structures (minor damage may be defined here as window breakage and more or less negligible damage to appendages of buildings). It is evident that substantial radiation doses are delivered to points far distant from the limits of minor blast damage.

Using a 10-megaton surface weapon as an example, it can be seen that the limit of minor damage (0.5 psi) is approximately 27 miles from ground zero. Lethal two-week outside doses of radiation (assumed to be about 600 Roentgens) extend as far downwind as 160 miles, and lower but substantial doses for nearly 500 miles distant.

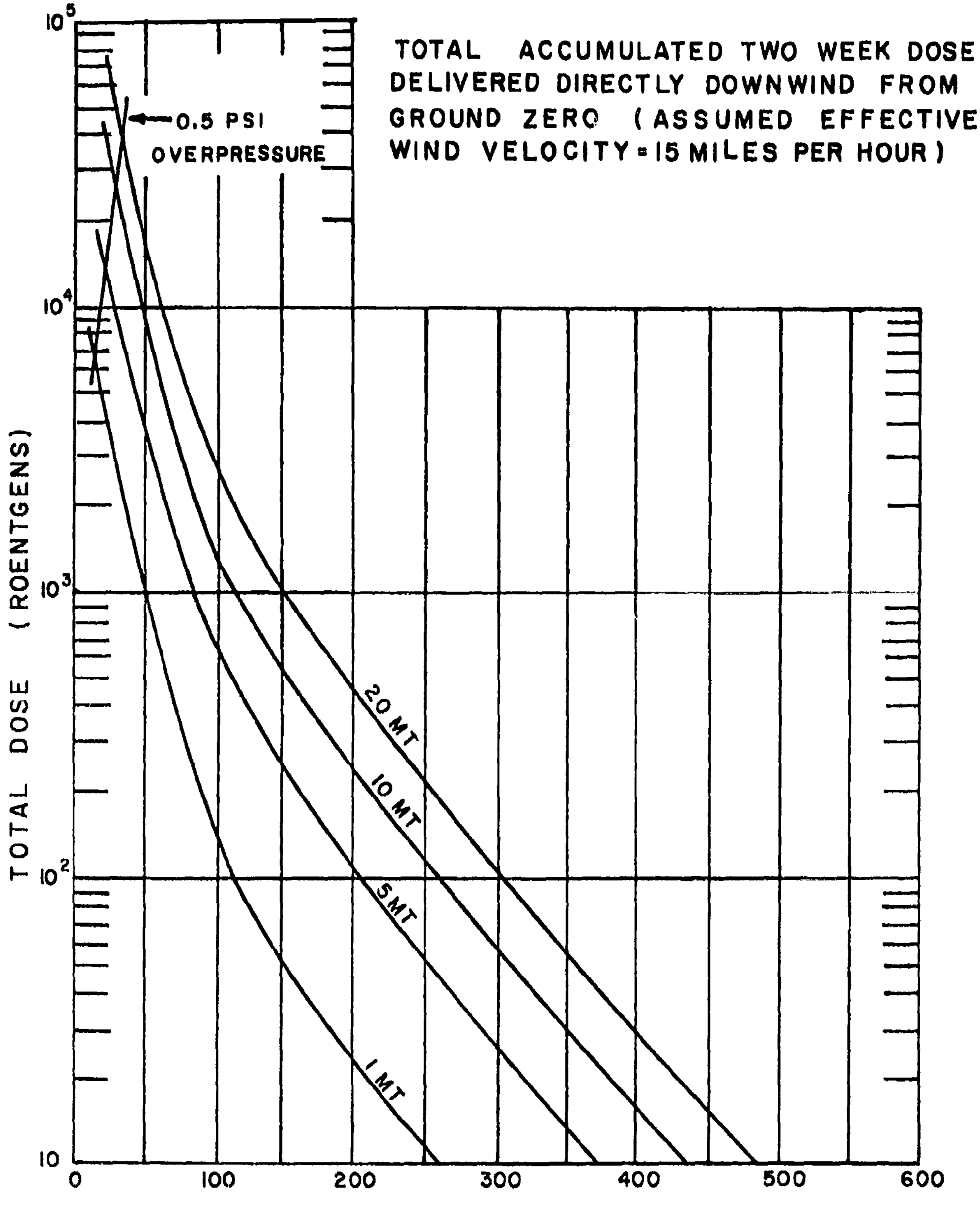

TOTAL ACCUMULATED TWO WEEK DOSE DELIVERED DIRECTLY DOWNWIND FROM GROUND ZERO (ASSUMED EFFECTIVE WIND VELOCITY = 15 MILES PER HOUR)
0.5 PSI OVERPRESSURE
20 MT
10 MT
5 MT
1 MT
TOTAL DOSE (ROENTGENS)
10^5
10^4
10^3
10^2
10
0
100
200
300
400
500
600
DISTANCE FROM GROUND ZERO (MILES)

FIGURE 2.1

2.3 BLAST DAMAGE

An approximation of the degree of damage suffered by exposure of ordinary above ground structures to a 10 M.T. blast is given in Fig. 2.2. The letters S, M and L define broad degrees of damage as follows: (1)*

S: Severe - Severe frame distortion, incipient collapse.

M: Moderate - Frame distorted moderately, interior partitions blown down.

L: Light - Windows and doors blown-in, light siding ripped off, interior partitions cracked.

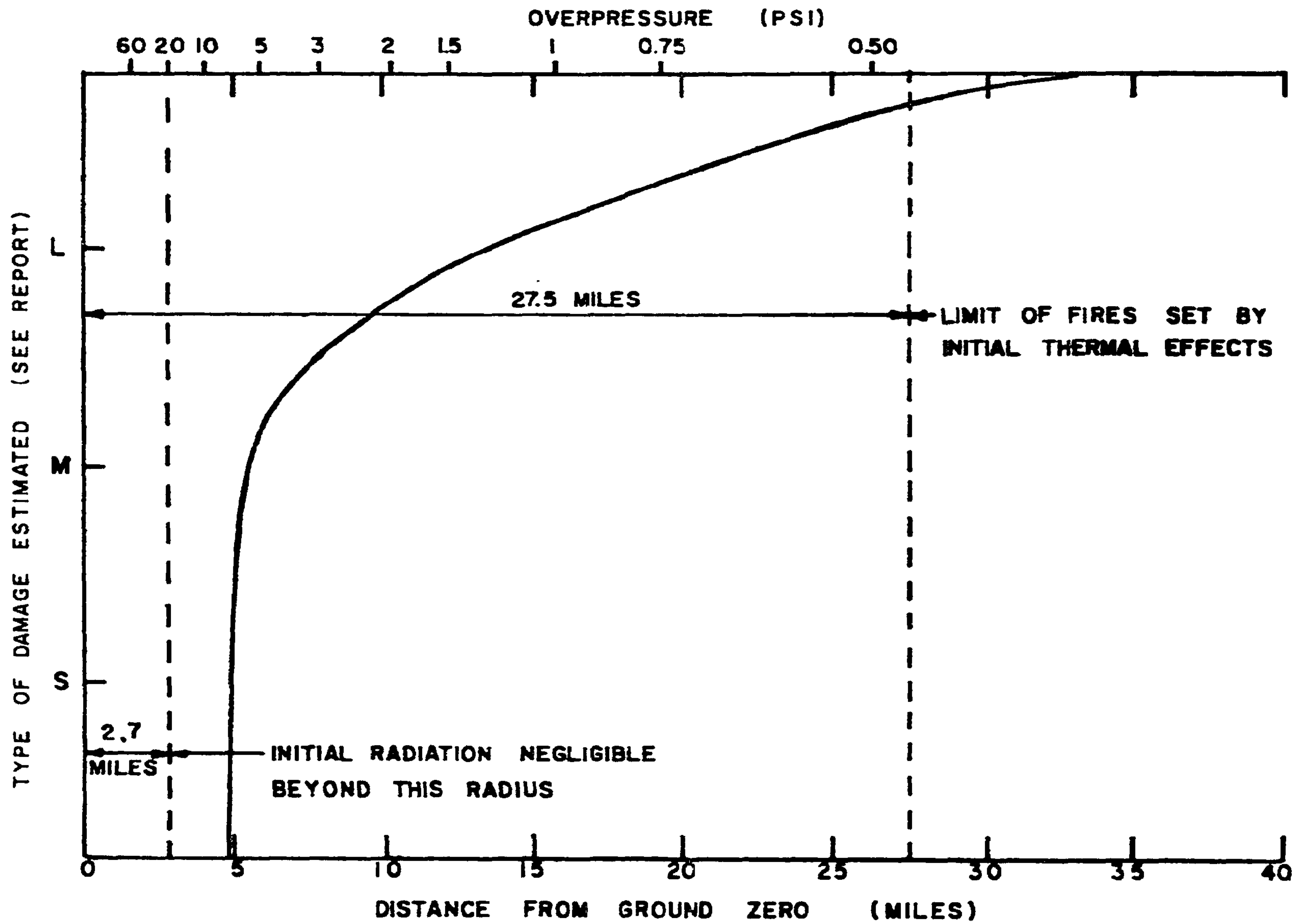
Severe and possibly Moderate damage is greater damage than these buildings can sustain and still maintain their usefulness as fallout shelters.

2.4 OTHER DIRECT EFFECTS

Along with estimated damage limits due to blast overpressure, other direct effects of a 10 M.T. surface blast are shown in Figure 2.3. With ground zero at the center, concentric limits are shown for discernible effects of:

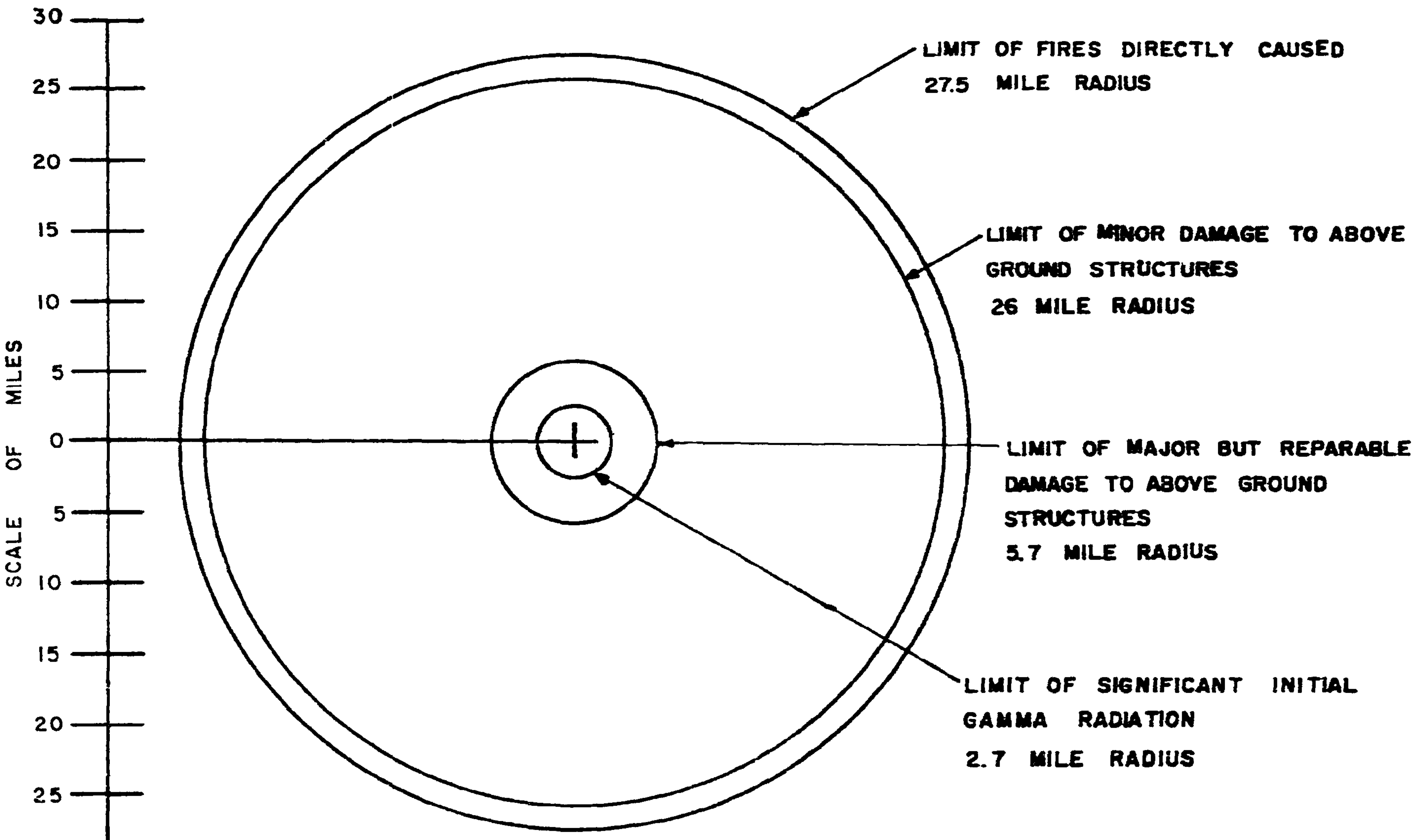
2.4.1 Fires caused by direct thermal radiation - These are the fires caused by ignition of combustible materials by the fireball-generated heat. Assuming no shielding effects of atmosphere, buildings, mountains, etc., it is expected that fires will be directly caused up to 27.5 miles from ground zero. This is

* See Page 232 for References.



ESTIMATED STRUCTURAL DAMAGE TO ABOVE GROUND STRUCTURES DUE TO 10 MT SURFACE BLAST

FIGURE 2.2



DIRECT EFFECTS OF A 10 MT SURFACE BLAST

FIGURE 2.3

based on a thermal energy level of 5 calories per sq. cm., which is the approximate ignition point of paper.

2.4.2 Initial Radiation - As indicated in the figure, the effect of initial radiation can be neglected beyond a 2.7 mile radius. This radiation includes neutron and initial gamma radiation, both of which are more or less instantaneous. (A dose of less than 10 REMS is considered negligible here).

These figures show that far more land area is affected by fallout than by any other effect, indirect or direct, of a nuclear detonation. This factor favors the survivability of many vital utilities having large and elaborate distribution systems, particularly those with a majority of underground lines, such as water, oil and gas pipes and electric conduits.

However, because of widespread contamination of watersheds, lakes and rivers, this same factor in the case of water systems is the major cause of vulnerability of the entire system. Since some 104,000,000 persons (approximately) in the United States are supplied with water derived wholly or in part from surface sources (2), effective countermeasures against fallout contamination of water are regarded as absolutely vital to civil defense planning.

SECTION 3

PROTECTION AND VULNERABILITY OF VITAL UTILITIES

3.1 CONSENSUS OF CURRENT EXISTING LITERATURE

Heavily depended upon for human survival and economic recovery, public utilities must be fully capable of continuity and of rapidly restoring interrupted service. Although already on an emergency footing to handle such natural disasters as storms, fires, floods, etc., utilities are now looking for ways to enhance their civil defense posture.

The problem of insuring survival and effective operation of utilities subsequent to a nuclear attack presents many common problems. Much study has already been devoted to analyzing these problems and developing effective counter measures. However, because of the elaborateness of utility distribution systems and the more or less fixed vulnerability of the supply components, few practicable measures can be taken in the way of physically hardening the system. Consequently, the trend of most studies is toward developing procedural methods of damage assessment, control and repair in the post-attack period and the protection of operating and maintenance personnel.

3.1.1 Recommendations - In accordance with the scope of work of this report, an extensive literature search was made to determine preferred methods of protecting vital facilities against fallout radiation. Basically, the investigation was conducted to determine those methods which are being considered and how they might be applied to the problem of protective water supply systems. A bibliography of nearly 400 references, compiled and searched for this phase of the study, appears in Appendix A.

A consensus of recommendations generally considered basic to a recovery program includes the following items:

3.1.1.1 Personnel Shelters - In the final analysis, the recovery of any utility is dependent upon its operating and maintenance personnel. Hence, providing and stocking of personnel shelters at the plant (or home base for field crews) is a positive requirement. The degree of protection to be provided, that is, fallout only or blast and fallout, is a point in question, but the tendency is toward blast shelters. This recommendation, seemingly paradoxical in intent since the plant or field office remains unhardened, is aimed at insuring personnel availability for operating and repairing those portions of the system still capable of providing service. Even though the field office or plant itself may be destroyed, it is recognized that surviving trained personnel may be able to effect certain repairs, by-passes or connections with other nearby utilities to continue service. Another argument for high protection against fallout radiation is that personnel should receive as little early fallout dose as possible so as to enable them to perform certain functions in outside contaminated areas without exceeding the hazardous limit.

3.1.1.2 A System of Damage Assessment - Exactly how this is to be accomplished in a contaminated area is not fully established, but there is general agreement as to its necessity in order to determine those repairs which are necessary, where they are to be made and what priority they should be given.

Depending on the post-attack damage situation and the condition of communications, some appraisals could be made by telephone or two-way radio communication with dispersed personnel or service users; or if radiation levels are low enough, a quick survey by helicopter or automobile teams may be utilized. Of course, the problem here is the extent and intensity of the radioactive contamination. While plans must be made to incorporate the hazard, the actual situation is so complex as to defy pre-attack estimates and must be assessed in the post-attack period. This survey is closely allied with item 3.1.1.3 (below).

3.1.1.3 A Radiological Survey - Such a survey would determine the extent of contaminated areas and the amount of time a repair crew can safely remain in a specific area. This is really within the jurisdictional area of local civil defense authorities, but close coordination with utility personnel is a requisite, since this data is basic to the formulation of further recovery steps.

Certain references are made to protected vehicles from which radiological surveys can be conducted, but these exist only in the planning and study phase and their availability in significant numbers is not considered likely enough for incorporation into present thinking.

3.1.1.4 A Stock Piling Program - This entails the stocking of essential materials and supplies necessary for operation and repair. This may be in the form of individual stock piles, joint arrangements with other nearby utilities or companies or a combination of the two.

3.1.1.5 A Mutual Aid Agreement - This would be an agreement with other nearby utilities whereby a connection may be established to provide emergency power, water, oil, gas, etc., and an organizational plan set up for immediate establishment of such a tie when needed. Actually, such agreements are common practice among utilities to handle natural disasters or peak overloads of service use, and often may require only confirmation in the form of a civil defense mutual aid pact.

3.1.1.6 Anticipation of Type and Degree of Damage Likely Under Various Conditions and Development of Countermeasures Required for Repair - The intent here is not to formulate a rigid master plan of repair, but to develop individual countermeasures against individual problems. Flexibility of the plan is a keynote since the anticipated damage conditions are so nebulous.

The plan's value derives from the fact that it becomes a readily available guide of countermeasures to be employed with minimum loss of time in strategy planning after the event.

3.2 PROBLEMS IN COMMON

The above principles can readily be adapted to all utility systems. The basic differences are encountered mostly in the detail planning under item 3.1.1.6., The Anticipation of Degree and Type of Damage.

Because of plant, equipment and product differences, it is natural to expect that essential components of various utilities react in different ways to various nuclear effects. Table 3.1 summarizes the effects of nuclear detonations as they concern oil, gas, telephone and telegraph, electric, steam and chilled water and water supply utilities. A subdivision of each supplier is made for the Supply and Distribution Components with a further breakdown into plant, personnel and product.

As can be expected, operating personnel vulnerability is of highest concern - their being directly effected by exposure to both direct and indirect effects.

Plant and equipment is the next highest consideration being directly effected by Blast, Thermal and Indirect Fire effects in both components for all utilities. Naturally, the severity of these effects upon individual components will vary depending upon the relationship of the component to the effect. Underground pipes, conduits and structures, for example, will be much more likely to survive than will their aboveground counterparts located at the same distance from ground zero.

Of final concern is the protection of the product itself. This is where essential differences occur in the civil defense planning or public utilities. While the product of all the utilities is unaffected by blast overpressure, it can be seen that oil and gas companies are concerned with the ignition of their product by thermal effects or indirect fires. On the

S U P P L Y   S Y S T E M

	UTILITY					
	Oil	Gas	Telephone & Telegraph	Electric	Steam & Chilled Water	Water
Overpressure:						
Plant	S	S	S	S	S	S
Personnel	S	S	S	S	S	S
Product	N	N	N	N	N	N
Initial Radiation:						
Plant	N	N	N	N	N	N
Personnel	S	S	S	S	S	S
Product	N	N	N	N	N	N
Thermal:						
Plant	S	S	S	S	S	S
Personnel	S	S	S	S	S	S
Product	S	S	N	N	N	N
Residual Radiation:						
Plant	N	N	N	N	N	N
Personnel	S	S	S	S	S	S
Product	N	N	S	S	N	S
Indirect Fire:						
Plant	S	S	S	S	S	S
Personnel	S	S	S	S	S	S
Product	S	S	N	N	N	N

Note: "N" denotes no or negligible effect. "S" denotes some effect; severity depending upon relative location of component to effect.

Individual Nuclear Effects on Selected Components of Utility Companies.

TABLE 3.1 - (Continued next page)

DISTRIBUTION SYSTEM

	UTILITY					
	Oil	Gas	Telephone & Telegraph	Electric	Steam & Chilled Water	Water
Overpressure:						
Plant	S	S	S	S	S	S
Personnel	S	S	S	S	S	S
Product	N	N	N	N	N	N
Initial Radiation:						
Plant	N	N	N	N	N	N
Personnel	S	S	S	S	S	S
Product	N	N	N	N	N	N
Thermal:						
Plant	S	S	S	S	S	S
Personnel	S	S	S	S	S	S
Product	S	S	N	N	N	N
Residual Radiation:						
Plant	N	N	N	N	N	N
Personnel	S	S	S	S	S	S
Product	N	N	S	S	N	N
Indirect Fire:						
Plant	S	S	S	S	S	S
Personnel	S	S	S	S	S	S
Product	S	S	N	N	N	N

Note: "N" denotes no or negligible effect. "S" denotes some effect; severity depending upon relative location of component to effect.

Individual Nuclear Effects on Selected Components of Utility Companies.

TABLE 3.1 - (Continued)

other hand, telephone and telegraph companies and, to a lesser extent, electric companies, must deal with possible temporary interference from radiation fields. To water supply systems, residual radiation presents the major hazard to the product.

Whereas those components of all other utilities surviving direct blast effects may possibly resume operation after repair, the problems of the water supply companies are unique in that their product is directly contaminated and rendered almost immediately non-potable by deposition of fallout. This problem is discussed further in Sections 5 and 6. For orientation purposes, the following brief resume of blast overpressure effects on various utilities is presented.

3.2.1 Gas Systems - Nevada tests carried out in 1955 have shown that gas distribution systems, with much of their piping underground, are highly resistant to blast overpressures of as much as 30 psi. Tests on domestic houses show that in general the service piping and equipment were intact and operable wherever the house itself did not suffer major damage (up to about 1.7 psi). (1)

Table 3.2 summarizes some probable blast damage to various elements from a 1.0 MT airburst.

3.2.2 Electric Distribution Systems - Extensive studies were conducted in 1955 to determine blast effects on electric utilities. These tests confirmed that at 5.0 psi overpressure (corresponding to 0.6 psi dynamic pressure) the power system was not significantly damaged. The type of damage was about similar to that caused by severe wind storms. The most vulnerable components appeared to be the suspension towers and poles which are sensitive to dynamic pressure loading, and flying debris and missiles.

Transformer substations remained relatively sound and capable of operation.

Underground cables can be expected to be highly blast-resistant except at terminal points where repairs could be relatively simple.

TABLE 3.2 (3)

BLAST DAMAGE TO GAS UTILITY COMPONENTS

Elements	ZONE A 0 to 1.8 mi (Up to 15 psi)	ZONE B 1.8 to 3.7 mi (5 to 15 psi)	ZONE C 3.7 to 5.5 mi (3 to 5 psi)	ZONE D 5.5 to 7.4 mi (1.7 to 3 psi)
Large fuel gas storage tanks	Destroyed	Probably destroyed	Possibly destroyed	Not destroyed
Gas mains	Some broken elements at ground zero and bridges	Not damaged except at bridges	Not damaged	Not damaged
Gas piping in buildings	Numerous breaks	Few breaks	Few breaks	Possibly no breaks

3.2.3 Oil and Other Similar Buried Pipe Lines -

Buried pipes would suffer little direct damage from blast overpressure, but blows at less critical points could reduce overall capacity to an estimated less than 50% of normal. Vulnerable locations are connections to above-ground installations such as refineries and bulk terminals which are generally located near major points of consumption. (1,22)

3.2.4 Water Systems -

3.2.4.1 Supply - Surface supplies are affected by possible damage to weirs and intakes which would impede extraction of water from rivers. Submerged water intake structures are subject to damage by water borne shock waves. Dams are subject to both water shock and blast overpressures which would tend to damage other components of the system. This degree of damage is generally associated with fallout levels of such magnitude as to pose a contamination threat to rivers and watersheds.

3.2.4.2 Treatment - Treatment plants, being mostly above ground structures are vulnerable to blast overpressures of more than about 3 to 5 psi. Whether or not operation can be continued depends largely on the condition of individual components within the plant such as pumps, valves, chlorination and other treatment equipment, electrical controls, etc. This equipment, being indoors, is most vulnerable to flying debris and missiles which would normally occur at overpressures of about 1 to 3 psi. Damage to buildings can be roughly estimated as follows: (1)

Overpressure	Estimated Damage
1 psi	Broken windows and skylights
3 psi	Ducts and ventilators deformed or broken off; light frame structural twisting, and cracking of walls and roofs.

Overpressure	Estimated Damage
5 psi	Collapse of roof and large sections of walls; deformed structural frames; rupture at exposed piping. Damage beyond repair of most electrical and mechanical equipment.

Damage to filter units may allow unfiltered water to gain access to filtered water, but this condition does not normally represent a major hazard as long as emergency disinfection is provided.

3.2.4.3 Distribution System - The 1945 Japanese bombing experience indicate that most damage is a result of loosened pipe joints, particularly in soft or filled ground (1,5). Even where a break has not actually occurred, a severe leak could undermine the pipe (or adjacent pipes) and cause a failure. (6) Other repercussions stem from possible contamination due to reduced pressure or a leak from an adjacent sewer.

In the 1949 Tacoma earthquake, the effects of which may in some respects be compared to the detonation of a nuclear weapon, there was only minor damage to water systems with rapid short pressure fluctuations due to surges. (7)

Steel mains are less susceptible to fracture than cast-iron pipes, especially over long lengths. The facility with which they can be cut by an acetylene torch also makes them more easily repaired. On the other hand, because of their relative thinness, these mains are more easily deformed than are cast-iron pipes.

Elevated tanks of average size and of current design would probably fail to remain in service after exposure to more than 1.0 psi, the weakest member being the roof. This is similarly the limiting factor in determining blast resistance of standpipes and reservoir structures, although some standpipes of average size would be expected to survive overpressures of about 5 psi. (8)

SECTION 4

THE EFFECT OF FALLOUT ON WATER SUPPLY SYSTEMS

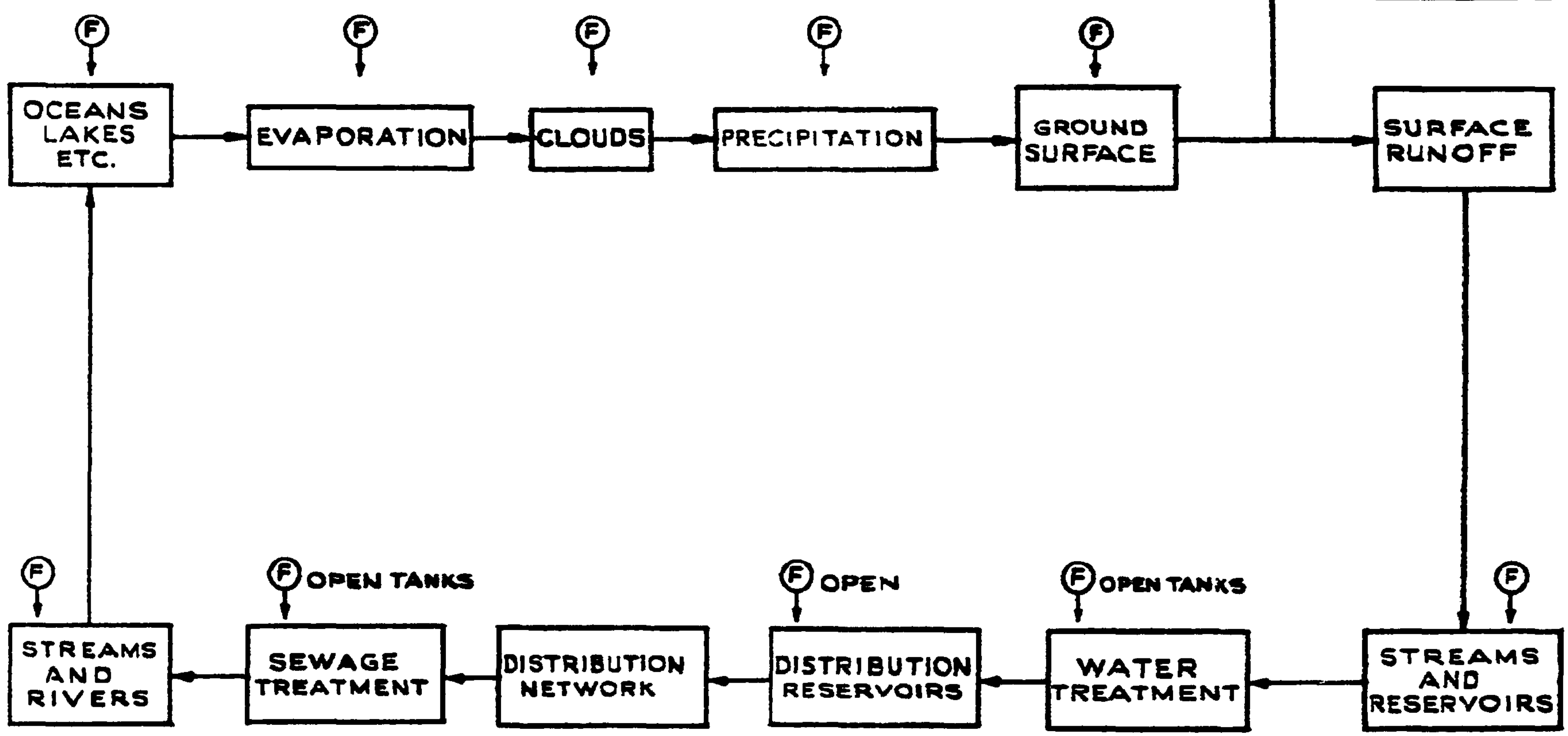
It is obvious that all open water surfaces are vulnerable in various degrees to direct contamination by radioactive fallout. In addition, radioactivity enters the water supply system through the natural processes of the water cycle (Figure 4.1). While evaporative water can be considered to be essentially free of radioactivity, water vapor in the air may be directly contaminated by fallout. Precipitation from this vapor would be likewise contaminated, as would be also precipitation falling through radioactive fallout suspended in the atmosphere.

This contaminated water finds its way to the water system directly or through runoff. In the latter case, additional quantities of radioactivity might be incurred through pick-up of fallout on the ground or through further deposition of fallout on streams and rivers.

In general, ground water will remain essentially uncontaminated; at least for some time subsequent to fallout deposition. This is due to the naturally slow movement of ground water, which impedes passage of contaminated water to the underground supply. In some cases, where the ground water is overlain by an impermeable layer, it could take years or even centuries for this water to show signs of radioactivity. During the process, most of the insoluble radioactivity and natural decay would significantly reduce the hazard.

4.1 HUMAN DOSE RELATIONSHIP

Human reaction to radiation is, at best, an inexact science based partly upon theoretical considerations and partly upon empirical observations. While these medical aspects are beyond the scope of this report, some understanding of the range of human tolerances



PORTIONS OF WATER CYCLE
VULNERABLE TO FALLOUT

Ⓕ FALLOUT

FIG.4.1

to radiation is required in order that the hazards of water contamination be evaluated in their proper perspective.

The danger of occupational exposure to radiation has led to extensive study of maximum permissible peacetime body burdens (17). These maximum concentrations, in air or water, for various radionuclides are generally given in microcuries per cubic centimeter (MC/CC) for a 40 or 168 hour week exposure.

Permissible concentrations in soluble and insoluble form to various body organs such as the gastro-intestinal tract, kidney, total body, liver, lung, bones and skin are also given.

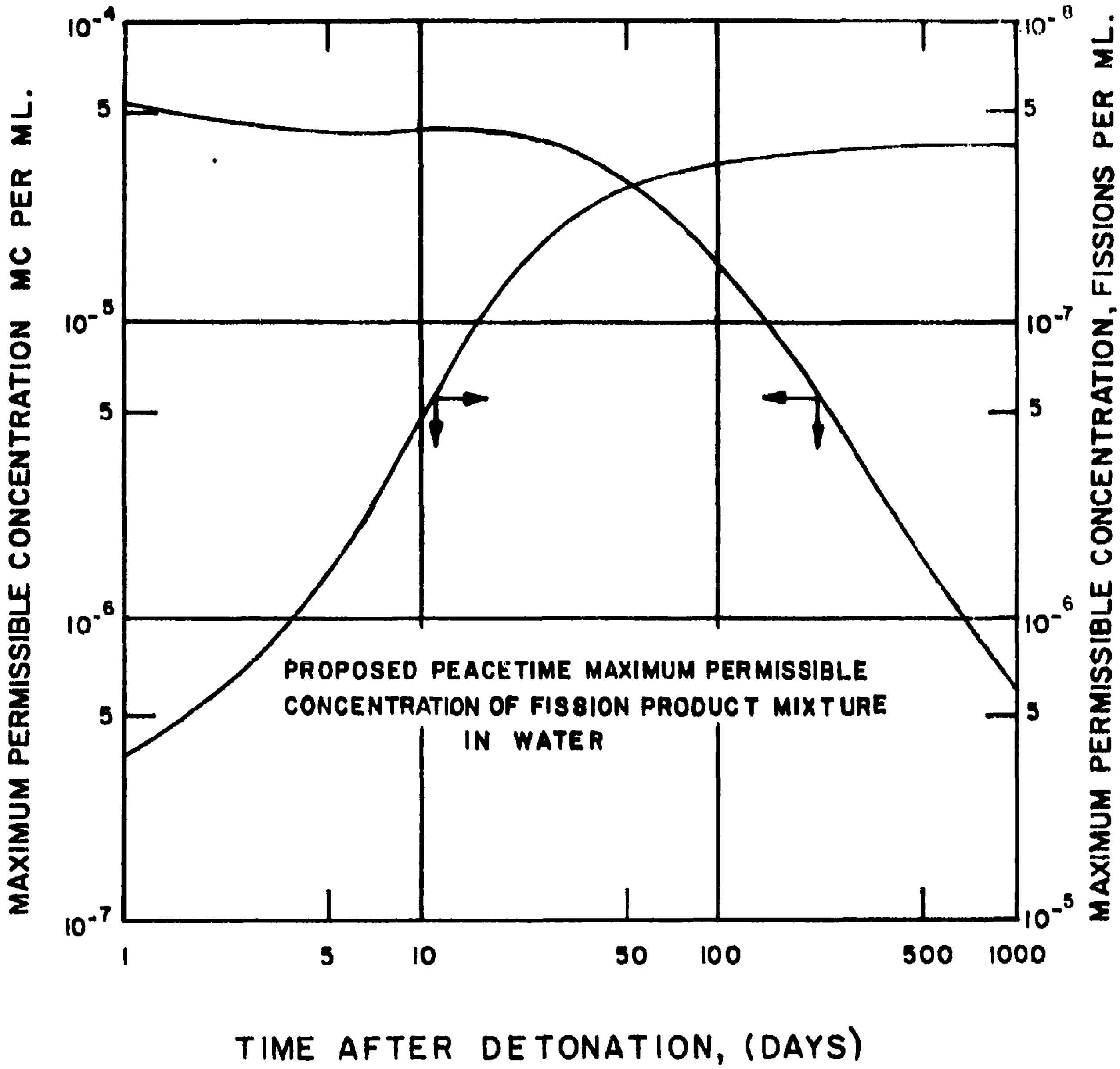
A proposed maximum permissible peacetime concentration of a fission product mixture based on a maximum permissible exposure of 0.6 rem per week to the thyroid, 0.56 rem per week to the bone and 0.3 rem per week to the gastrointestinal tract is shown in Figure 4.2.

The National Committee on Radiation Protection has published a table of maximum permissible concentrations (MPC) for many important isotopes. The MPC in MC/CC for various radioisotopes represents the values considered safe in water for life time consumption (18).

The Atomic Energy Commission and U. S. Public Health Service have suggested, in past reports, disaster limits of 9×10^{-2} microcuries per cubic centimeter (MC/CC) for consumption of drinking water during a 10 day period immediately following a nuclear detonation, and 3×10^{-2} MC/CC for a 30 day period. These limits are based upon beta and yamma radioactivity.

While further study is required to ascertain the applicability of these standards to the wide range of post attack conditions, they represent the latest qualified information on permissible radiation limits in drinking water. Their use in this report is, again, as a "yardstick" by which to compare the effect and significance of various parameters upon potability.

The relationship between fallout radiation intensity and ingested body dose is demonstrated by the following example.



FROM HAWKINS, REF. (19)

FIGURE 4.2

EXAMPLE 4.1

Fallout having a radiation intensity of 3,000 r/hr. at 1 hr. is deposited on an open reservoir 30 feet deep. Determine the dose to the gastrointestinal tract due to the consumption of 1,000 CC of this water 10-days after detonation.

Solution

The dose rate of 3,000 r/hr. at 1 hr. is equivalent to 6×10^{15} fissions/sq. ft. (Table 4.1)

$$\frac{6 \times 10^{15} \text{ fissions/sq. ft.}}{30 \text{ feet}} = 2 \times 10^{14} \text{ fissions/cu. ft.}$$

$$2 \times 10^{14} \text{ fissions/cu. ft.} \times \frac{9.0 \times 10^{-4} \text{ MC*}}{10^{8} \text{ fissions}} \times 3.54 \times 10^{-5} \frac{\text{cu.ft.}}{\text{CC}}$$

$$= 6.3 \times 10^{-2} \text{ MC/CC}$$

(* from Figure 4.3)

$$6.3 \times 10^{-2} \text{ MC/CC} \times 1000 \text{ CC} \times 2.7 \times 10^{-2} \text{ rem/MC*} = 1.7 \text{ rem}$$

(* from Figure 4.4)

Table 4.1 indicates an anticipated relationship between radiation intensity and quantity of fissioned material. For this example, it is assumed that the fallout is distributed uniformly throughout the water. While this is not an exact representation of the fallout distribution, it permits computation of the contamination expressed in terms of fissions per cubic foot. Figure 4.3 given the relationship between microcuries of fallout mixture and fissions at various times after detonation, including radioactive decay.

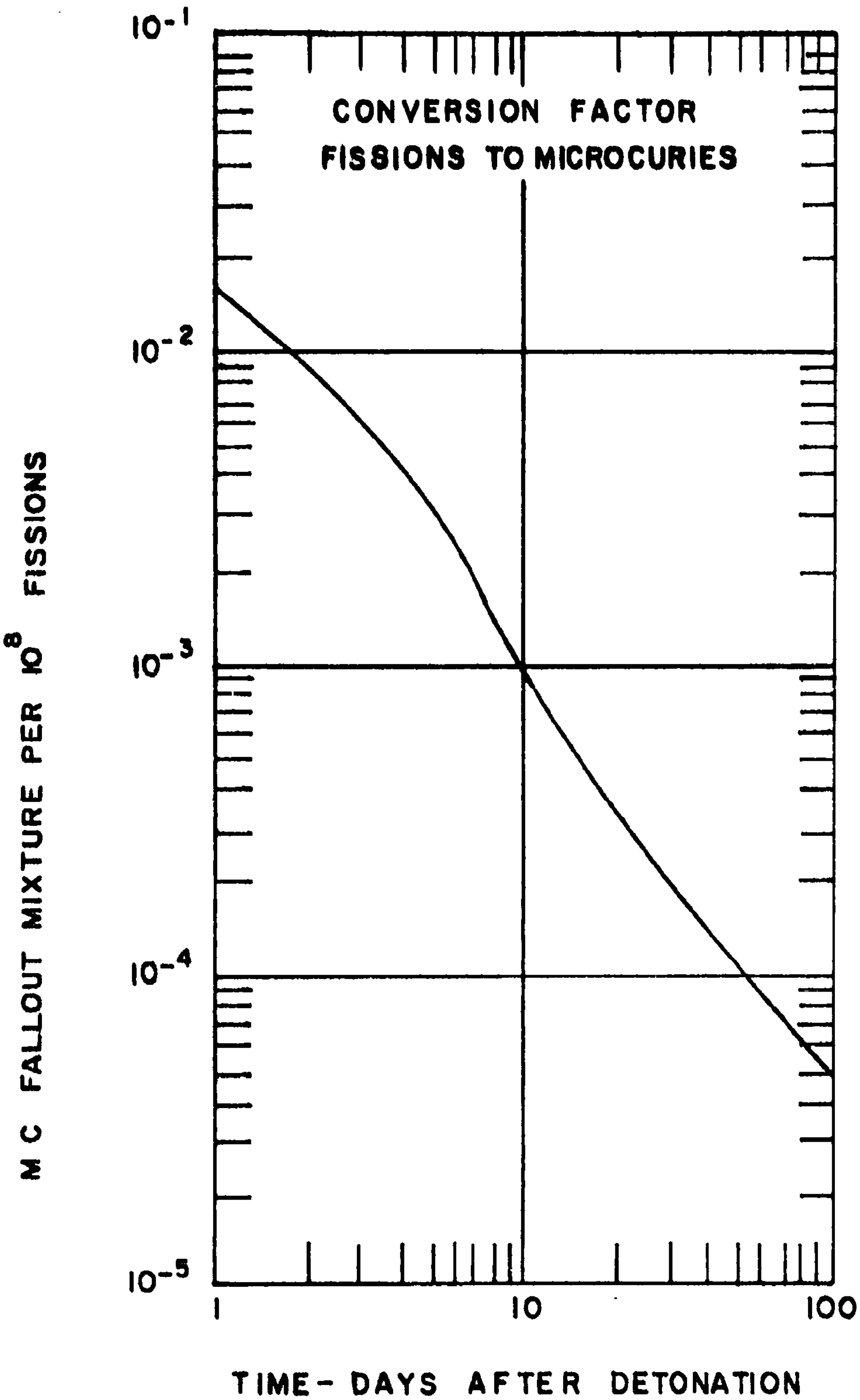
The contamination in the example is computed to be 6.3×10^{-2} microcuries per cubic centimeter and in this form can be compared with standards set-up for potable water. The internal dose due to the ingestion

TABLE 4.1

Anticipated Relationship Between Radiation Intensity and Quantity of Fallout Deposition from a Megaton Land Surface Detonation.*

Standard Intensity r/hr. at 1 hour	Deposited Mass of Fallout gms/ft^2	Quantity of Fissioned Material		
		KT/sq. mile	fissions/sq.ft.	fissions/sq.in.
100	3	0.04	2×10^{14}	2.2×10^{11}
300	9	0.12	6×10^{14}	6.6×10^{11}
1,000	30	0.4	2×10^{15}	2.2×10^{12}
3,000	90	1.2	6×10^{15}	6.6×10^{12}
10,000	300	4.0	2×10^{16}	2.2×10^{13}

* From Reference (19)



FROM HAWKINS, REF. (19)

FIGURE 4.3

of 1 microcurie of fallout mixture is given in Figure 4.4. The dose in rem is expressed as "committed 365 days dose" which is the dose that will result in the subsequent year due to the ingestion of 1 microcurie (20). For example, the dose to the gastrointestinal tract due to the ingestion of 1 microcurie of fallout mixture 10 days after detonation is 2.7 x 10^{-2} rem.

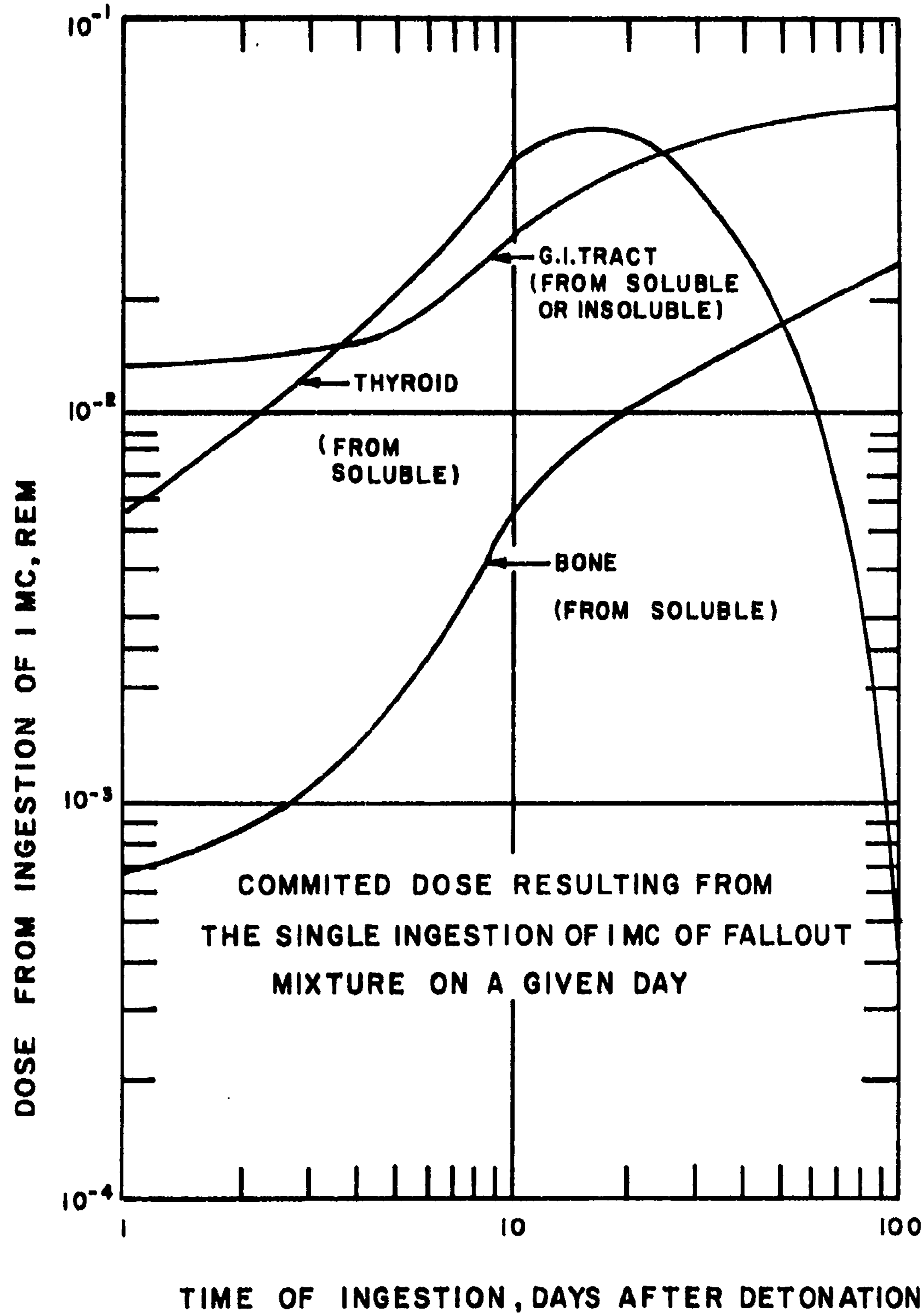
In Example 4.1, the ingestion, 10 days after detonation, of 1,000 cubic centimeters of water contaminated by a fallout mixture results in a dose of 1.7 rem to the gastrointestinal tract. The dose to the thyroid and bone can also be computed using Figure 4.4

It should be noted that this example considers only doses due to ingestion of contamination and that for the total body effect the external dose must be considered.

Peacetime and wartime standards for water are established by considering the effects upon the body of various radioisotopes and deriving maximum permissible concentrations in terms of microcuries per cubic centimeter. In this report, contamination will be considered in terms of microcuries per cubic centimeter and of an assumed mixed fission product to facilitate easy comparison with established standards.

4.2 THE DIRECT CONTAMINATION OF UNCOVERED RESERVOIRS BY RADIOACTIVE FALLOUT

Of primary importance in a vulnerability study of a water system is the determination of the extent and degree of contamination. However, the multiplicity of significant parameters precludes accurate estimation of the post-attack fallout condition. Factors which affect the degree of fallout contamination include the size, type, number, and location of detonations and the meteorological and geophysical conditions. The effect of fallout upon uncovered reservoirs is similarly affected by various factors including radiation intensity, reservoir depth, type and solubility of fallout particles



FROM HAWKINS, REF. (19)

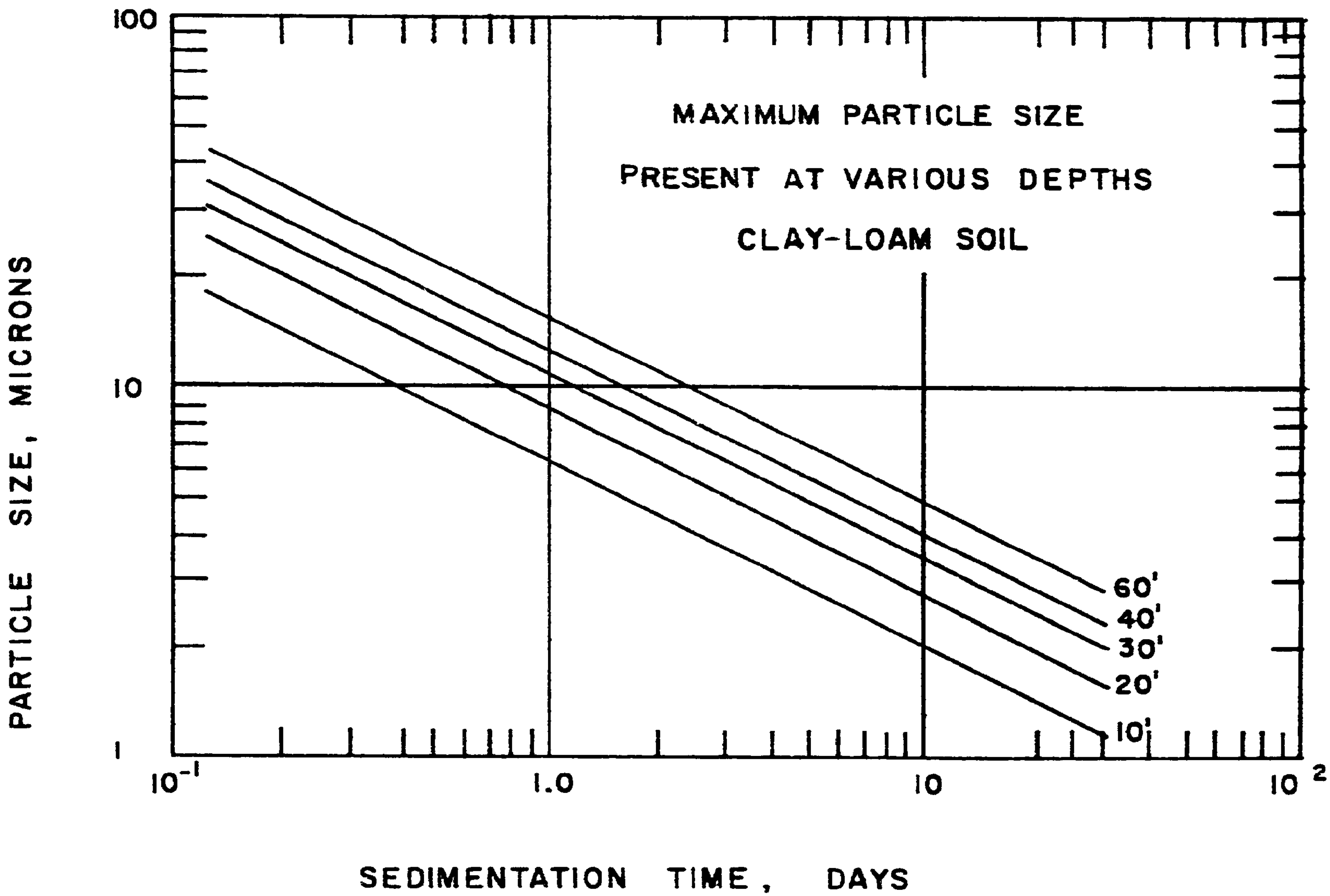
FIGURE 4.4

and time elapsed since detonation. In this section, some of these parameters will be examined. The intent here is to demonstrate the effect and significance of individual factors upon potability as compared with other factors. The results are intended to be qualitative rather than quantative particularly in view of the general nature of the "yardsticks" by which potability is measured.

4.2.1 The Effect of Sedimentation

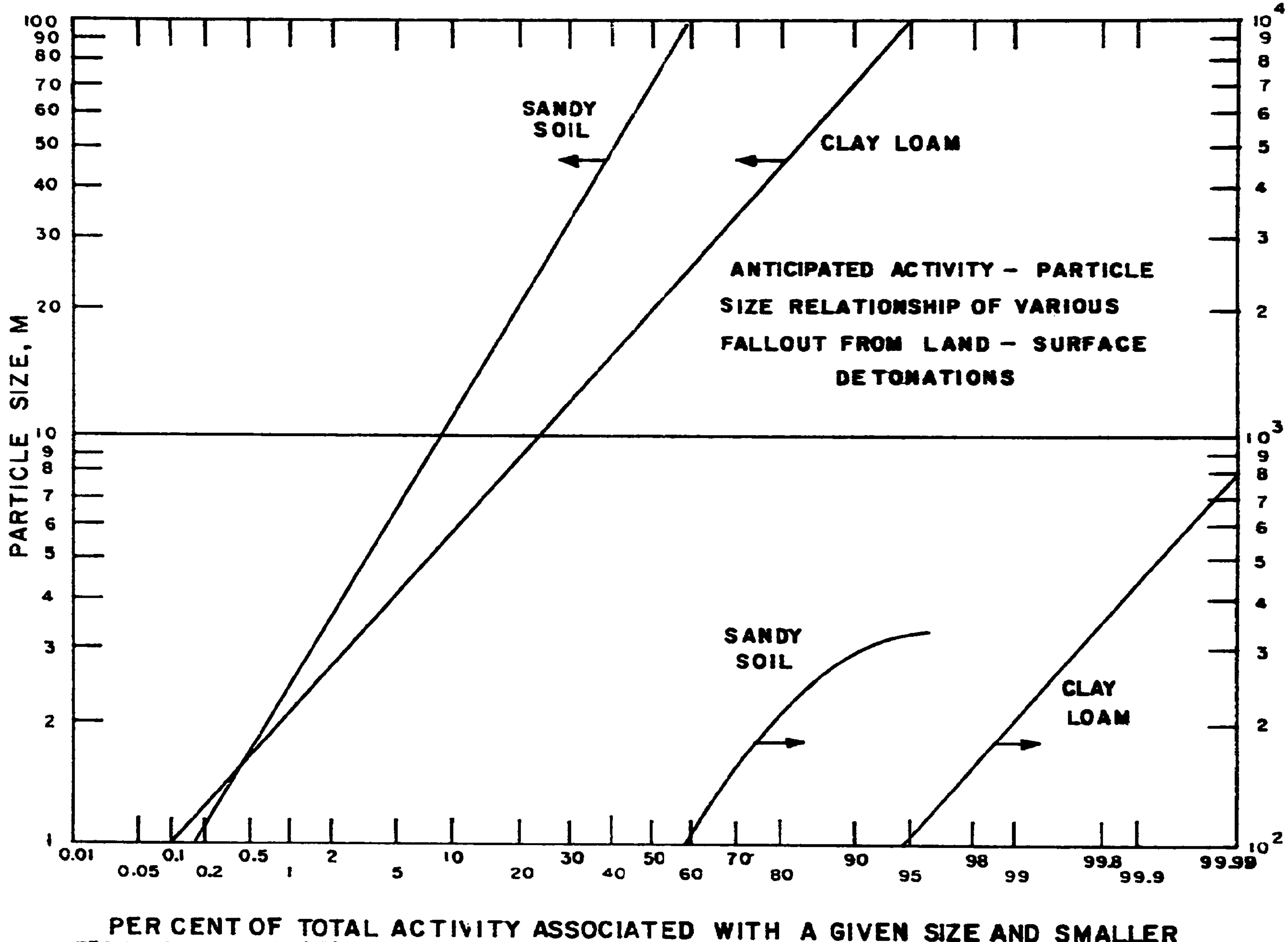
Fallout due to a surface burst will be composed primarily of particles of soil which have been fused with radioactive material. It is anticipated, therefore, that fallout occuring on a reservoir will tend to settle to the bottom in a manner similar to that of natural soil. The rate of sedimentation has been computed taking into account the forces of gravity, buoyancy and drag. (19) Figure 4.5 indicates the maximum particle size of clay loam soil that will be found at various depths in a reservoir as a function of time after initial introduction into the water. Larger particles will settle faster and be found at greater depths. The amount of radioactivity assumed to be associated with various particle sizes is indicated in Figure 4.6. Figure 4.7, based on Figures 4.5 and 4.6, indicates the contamination in a reservoir at various depths as a function of time. (19) This set of curves is predicated in a surface concentration of 3,000 r/hr. at 1 hr. which is assumed equivalent to 6×10^{15} fissions per square foot and is in conformity with a two-week exposure dose of 10,000 Roentgens. The curves indicate only the contamination due to the insoluble radioactive material (assumed 90 percent in this case).

Figure 4.8 indicates the contamination of water near the bottom in reservoirs of various depths. The soluble radioactive material is assumed to be distributed equally throughout the reservoir, and the insoluble portion is assumed to settle in accordance with Figure 4.7. The total contamination due to soluble and insoluble material is also indicated in Figure 4.8. Present estimates are that close-in fallout is approximately from 1 to 10 percent soluble, and intermediate fallout is about 50 percent soluble. Use of these figures in determining total contamination of the water is embodied in the following examples:



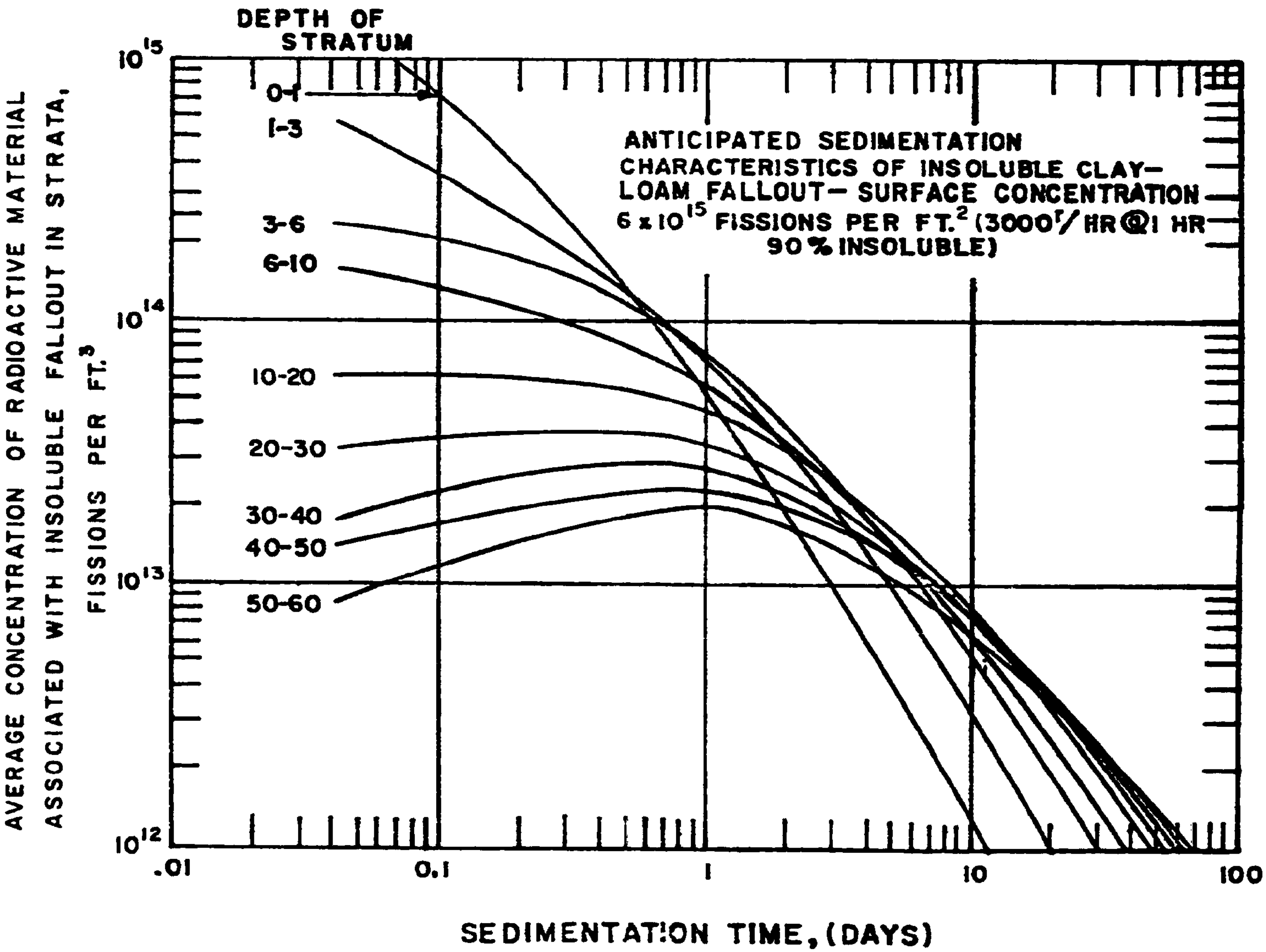
FROM HAWKINS, REF. (19)

FIGURE .5



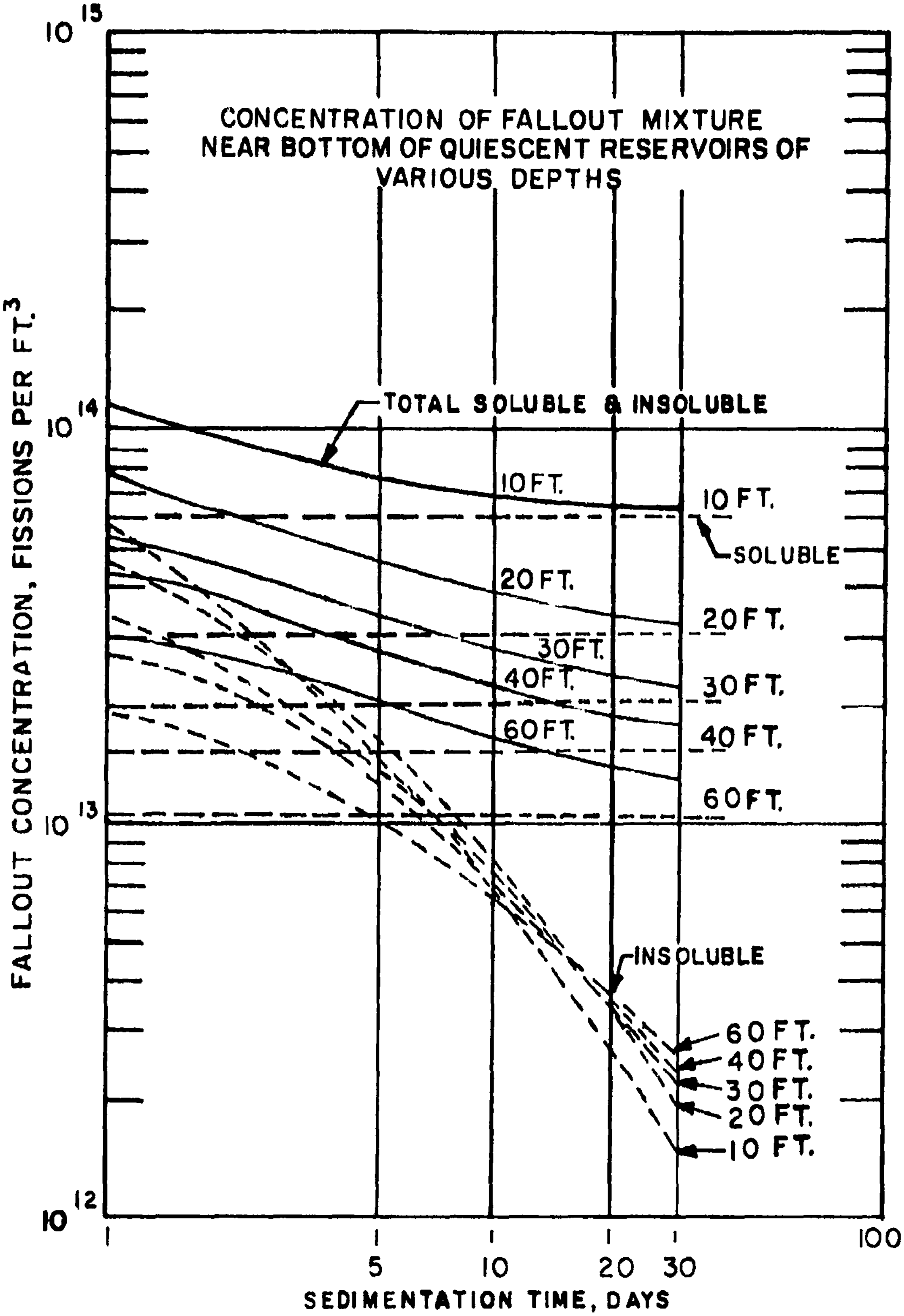
FROM HAWKINS, REF. (19)

FIGURE 6



FROM HAWKINS, REF (19)

FIGURE 7



CLAY LOAM FALLOUT- 10% SOLUBLE

SURFACE CONCENTRATION - 3000 r/ HOUR @ 1 HOUR.

FROM HAWKINS, REF. (19) FIGURE .8

EXAMPLE 4.2

An uncovered reservoir 30 feet deep is contaminated by fallout at a level of 3,000 r/hr. at 1 hr. (assumed equivalent to 6×10^{15} fissions per square foot). The fallout is clay-loam and 10 percent soluble. Find the concentration of radioactivity near the bottom of the reservoir 10 days after detonation.

Soluble Portion

$$6 \times 10^{15} \text{ fis/ft}^2 \times \frac{1}{30 \text{ ft.}} \times (.10 \text{ soluble}) = 2 \times 10^{13} \text{ fis/ft}^3$$

$$2 \times 10^{13} \text{ fis/ft}^3 \times \frac{9.0 \times 10^{-4} \text{ MC*}}{10^8 \text{ fissions}} \times 3.54 \times 10^{-5} \text{ ft.}^3/\text{CC}$$
$$= 6.4 \times 10^{-3} \text{ MC/CC}$$

(* from Figure 4.3)

Insoluble Portinn

$$7 \times 10^{12} \text{ fis/ft}^3\text{*} \times \frac{9.0 \times 10^{-4} \text{ MC}}{10^8 \text{ fissions}} \times 3.54 \times 10^{-5} \frac{\text{ft}^3}{\text{CC}}$$
$$= 2.2 \times 10^{-3} \text{ MC/CC}$$

(* from Figure 4.7)

Total Contamination $= 8.6 \times 10^{-3}$ MC/CC

Alternate Method

$$2.7 \times 10^{13} \text{ fis/ft}^3\text{*} \times \frac{9.0 \times 10^{-4} \text{ MC}}{10^8 \text{ fissions}} \times 3.54 \times 10^{-5} \frac{\text{ft}^3}{\text{CC}}$$
$$= 8.6 \times 10\text{-}3 \text{ MC/CC}$$

(* from Figure 4.8)

The soluble portion is assumed to be equally distributed throughout the reservoir. Contamination is then computed in terms of fission per cubic foot and converted to microcuries per cubic centimeter.

The contamination due to the insoluble portion depends upon the sedimentation characteristics of the fallout and is taken from Figure 4.7. The total contamination due to soluble and insoluble fallout may be obtained from Figure 4.8 and converted to MC/CC.

The total contamination in Example 4.2, including the effect of sedimentation, is 8.6×10^{-3} MC/CC. The contamination in Example 4.1, which is the same problem ignoring the effect of sedimentation, is 6.3×10^{-2} MC/CC. In this case, a sedimentation period of 10 days reduced contamination by 87 percent.

EXAMPLE 4.3

If the fallout intensity in Example 4.2 is reduced to 300 r/hr. at 1 hr., and all other factors remain unchanged, find the contamination after 10 days.

$$8.6 \times 10^{-3} \text{ MC/CC}^{*} \times 300/3000 = 8.6 \times 10^{-4} \text{ MC/CC}$$

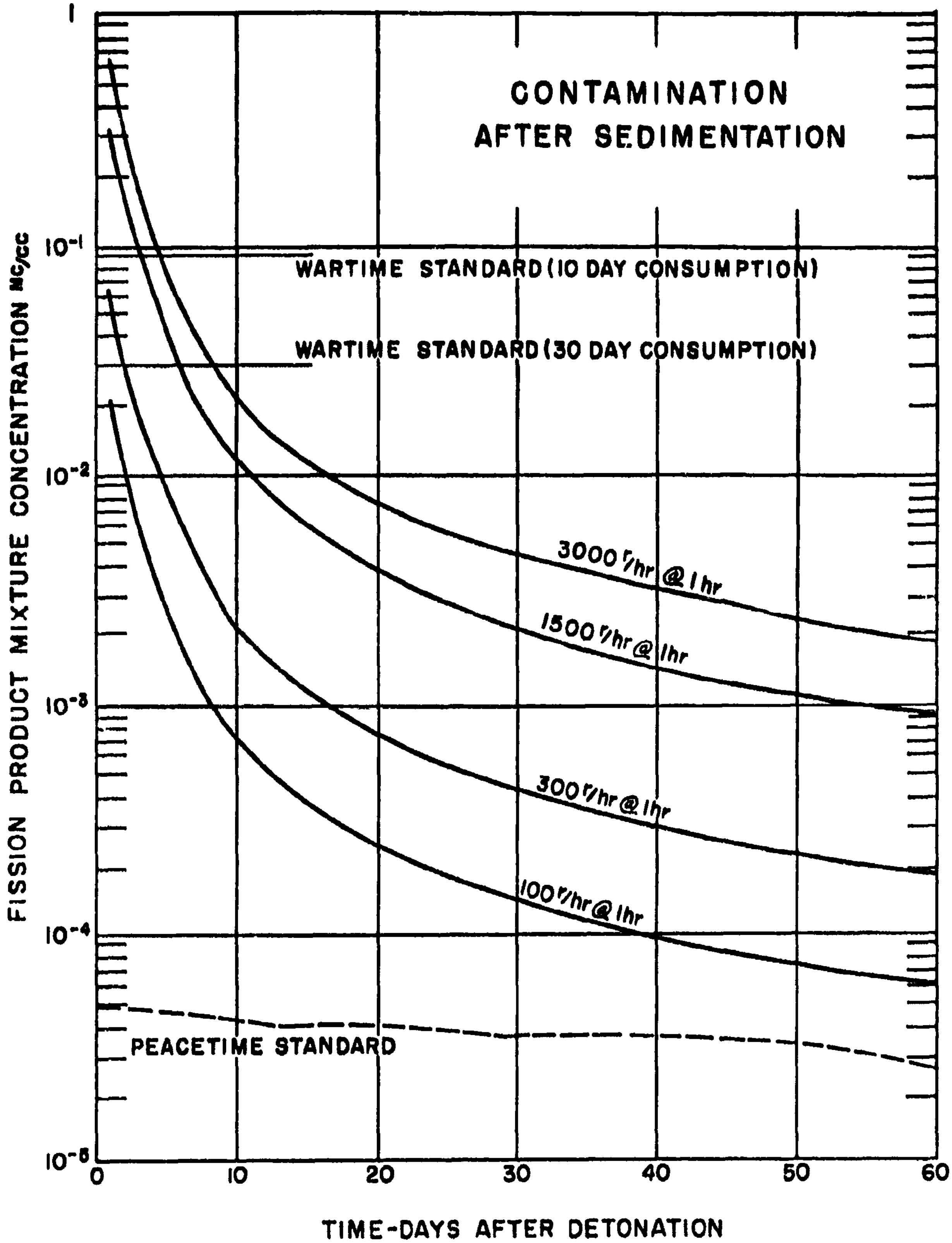
(* from Example 4.2)

It is assumed here that contamination is directly proportional to the level of radiation intensity at the surface of the reservoir.

4.2.2 Contamination After Sedimentation in Reservoirs of Various Depth

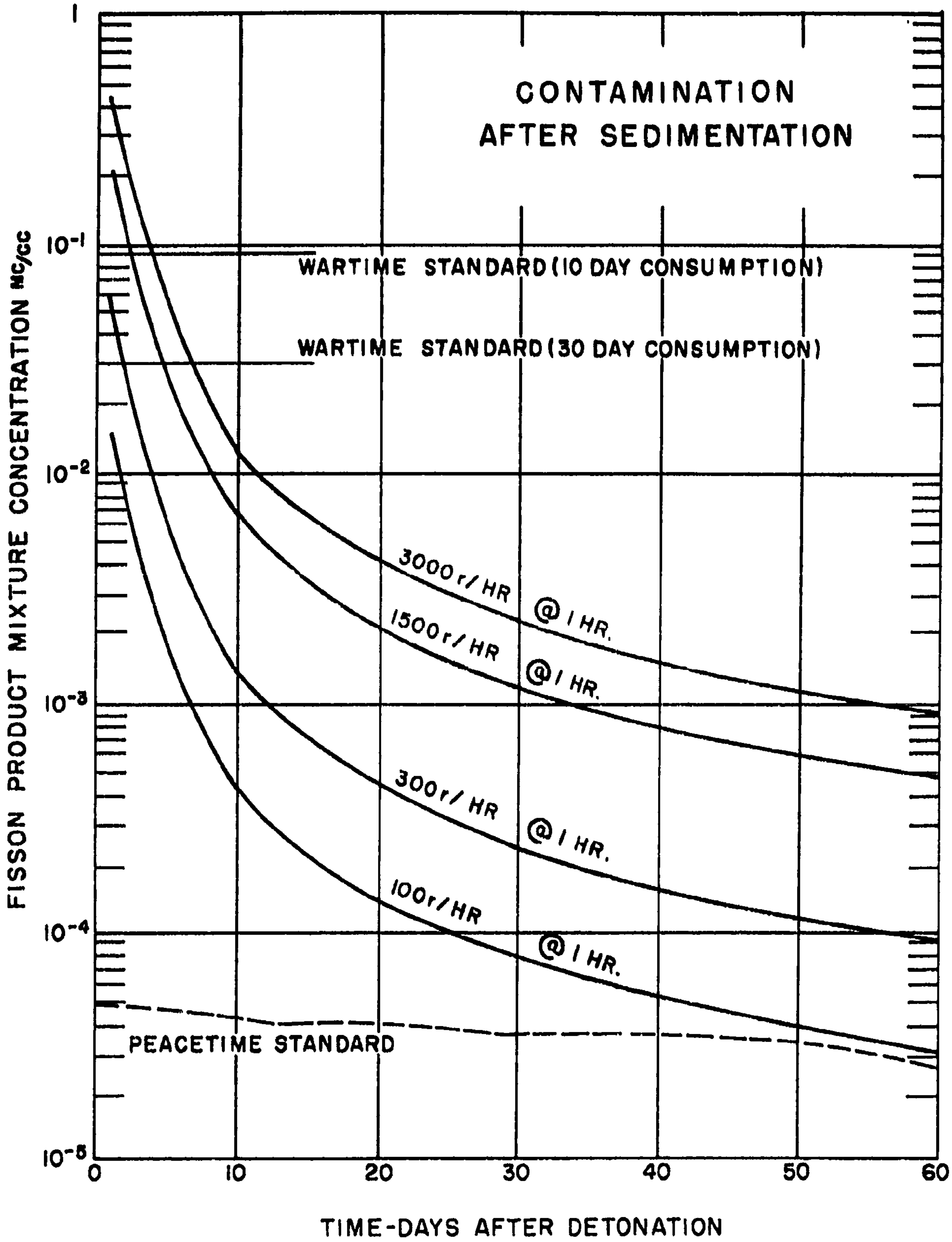
The contamination near the bottom of reservoirs 10, 20, 30 and 60 feet deep was computed using the methods demonstrated in Example 4.2 and 4.3. Figures 4.9, 4.10, 4.11 and 4.12 indicate contamination as a function of time after detonation for various radiation intensities and reservoir depths. Fallout is assumed to be 10 percent soluble clay-loam. Tentative wartime and proposed peacetime standards for a fission product mixture are superimposed for comparison.

As to be expected, a general decrease in contamination with time is apparent. While this is due primarily to radioactive decay, sedimentation of the insoluble fallout particles also has a contributing effect.



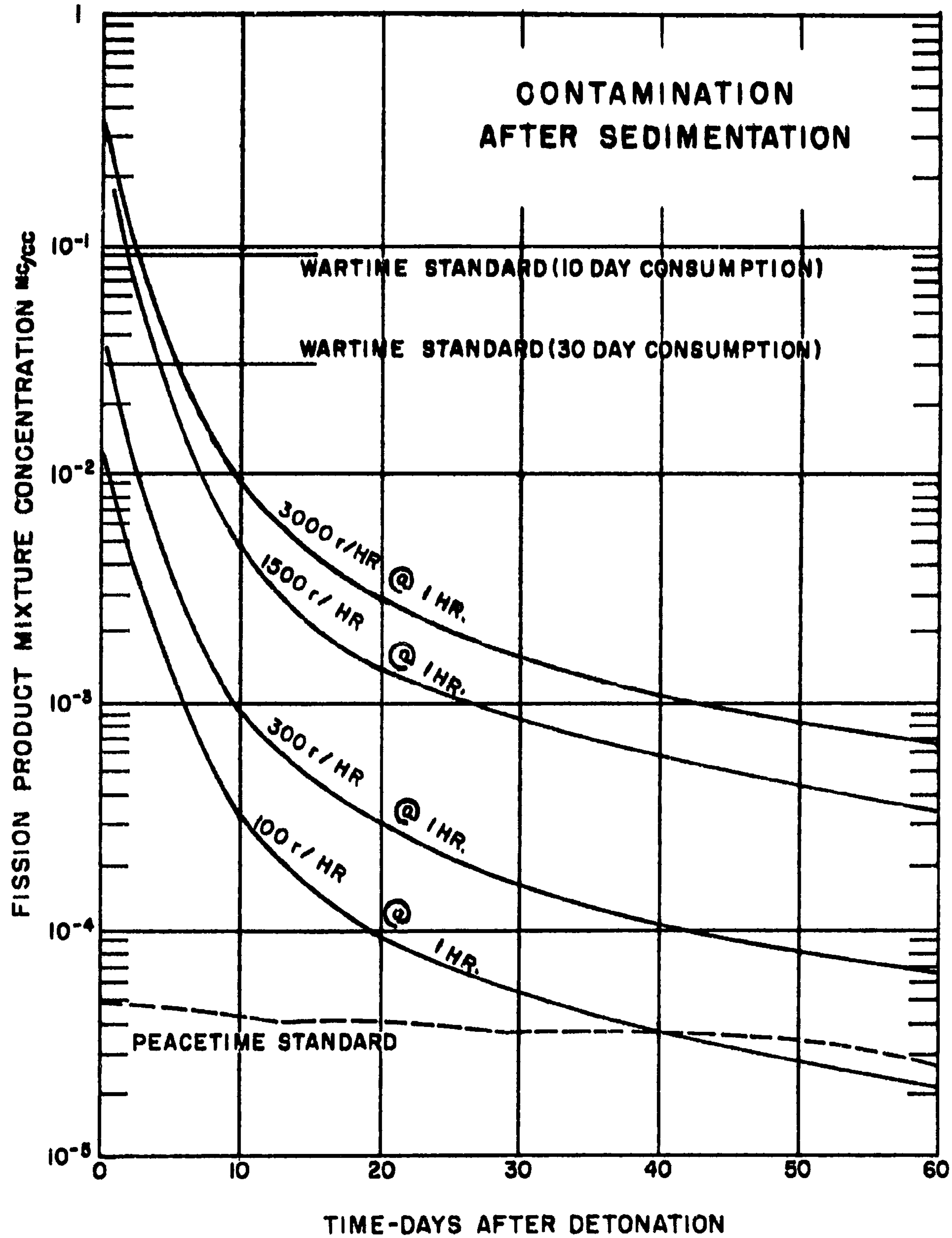
CLAY LOAM FALLOUT ON 10 FT. DEEP RESERVOIR-10% SOLUBLE

FIGURE 4.9



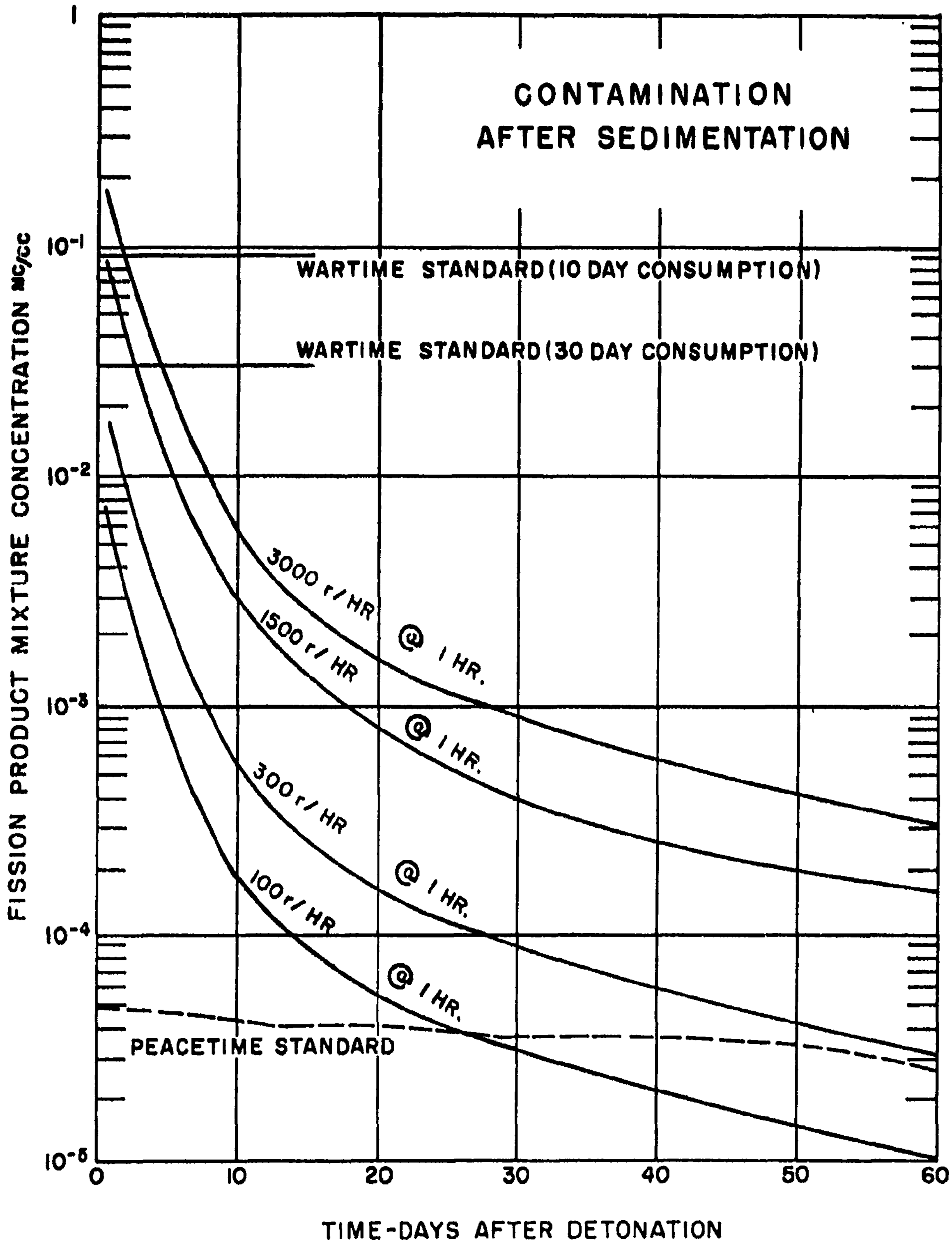
CLAY-LOAM FALLOUT ON 20 FT DEEP RESERVOIR-10% SOLUBLE

FIGURE 4.10



CLAY LOAM FALLOUT ON 30 FT. DEEP RESERVOIR-10% SOLUBLE

FIGURE 4.11



CLAY LOAM FALLOUT ON 60 FT. DEEP RESERVOIR-10% SOLUBLE

FIGURE 4.12

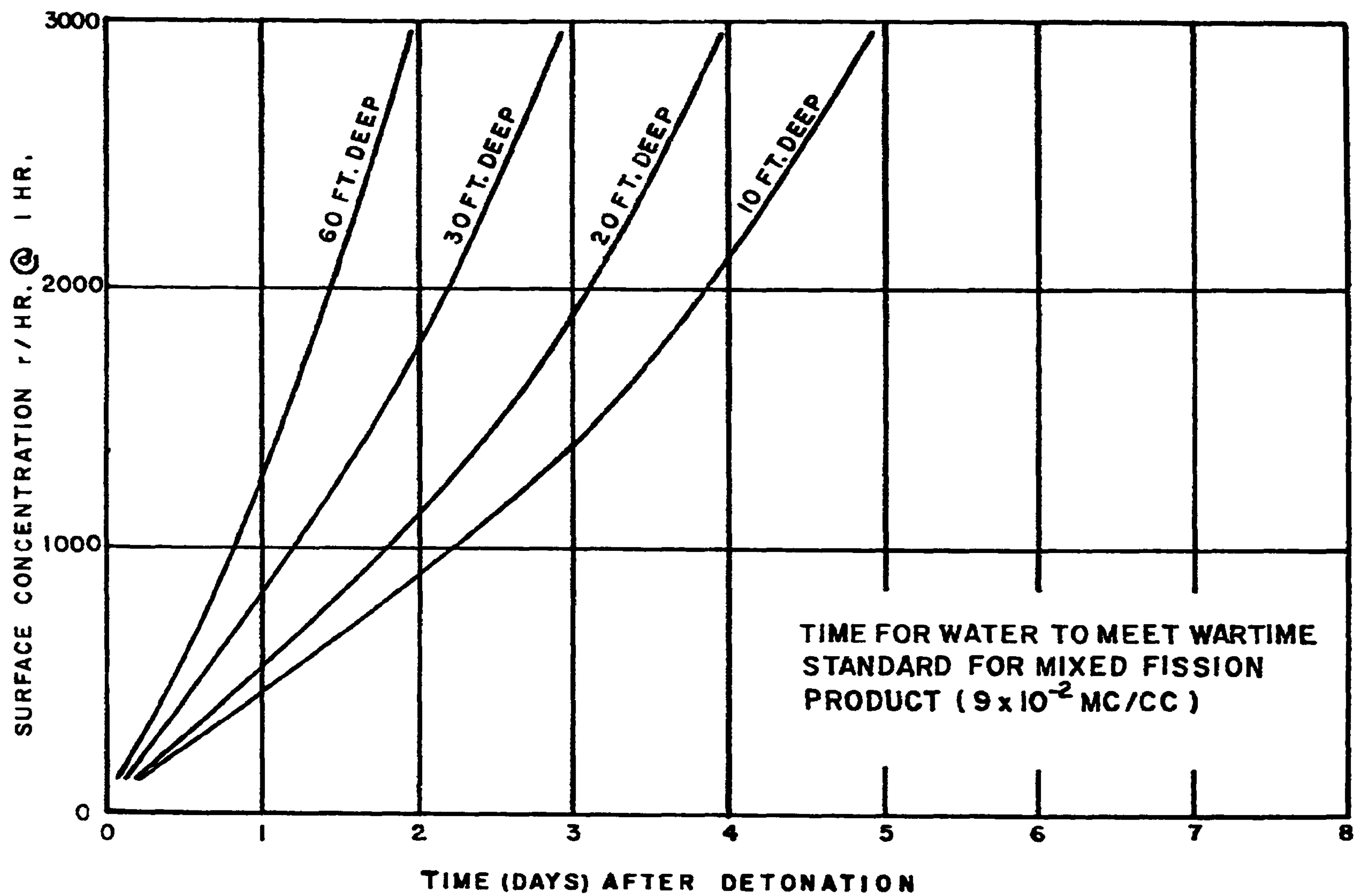
The effect of dilution is indicated by the decrease in contamination with increase in reservoir depth. These curves indicate the degree of contamination near the bottom of a reservoir. However, for any individual reservoir, the contamination will not vary significantly with depth after the first few days. This is illustrated in more detail in Section 5 (Selective Withdrawal).

In all the cases considered, water would meet established wartime standards for 10 or 30 day consumption in a relatively short time. The time required after detonation for water to reach these standards is indicated in Figures 4.13 and 4.14. The worst condition is encountered with a heavy fallout concentration on a shallow reservoir. For example, approximately 8 days would be required before water, in a 10 foot deep reservoir, subjected to a radiation intensity of 3,000 r/hr. at 1 hour would reach the wartime standard for 30 day consumption (3.0×10^{-2} MC/CC).

Lower fallout concentrations on deeper reservoirs would result in less contamination, and in some cases the water would even meet peacetime standards within a few weeks. As a general rule, it can be said that, for the condition of fallout occurring directly on an open reservoir, wartime standards can be attained with relative facility. However, such water is only suitable for 10 to 30 day emergency consumption, and provision must be made for supplying potable water after the expiration of this time. For reasonably high radiation intensities (say above 1500 r/hr. at 1 hr.), the action of sedimentation, dilution and decay will not, without further treatment, provide water satisfactory for consumption during an extended period of time.

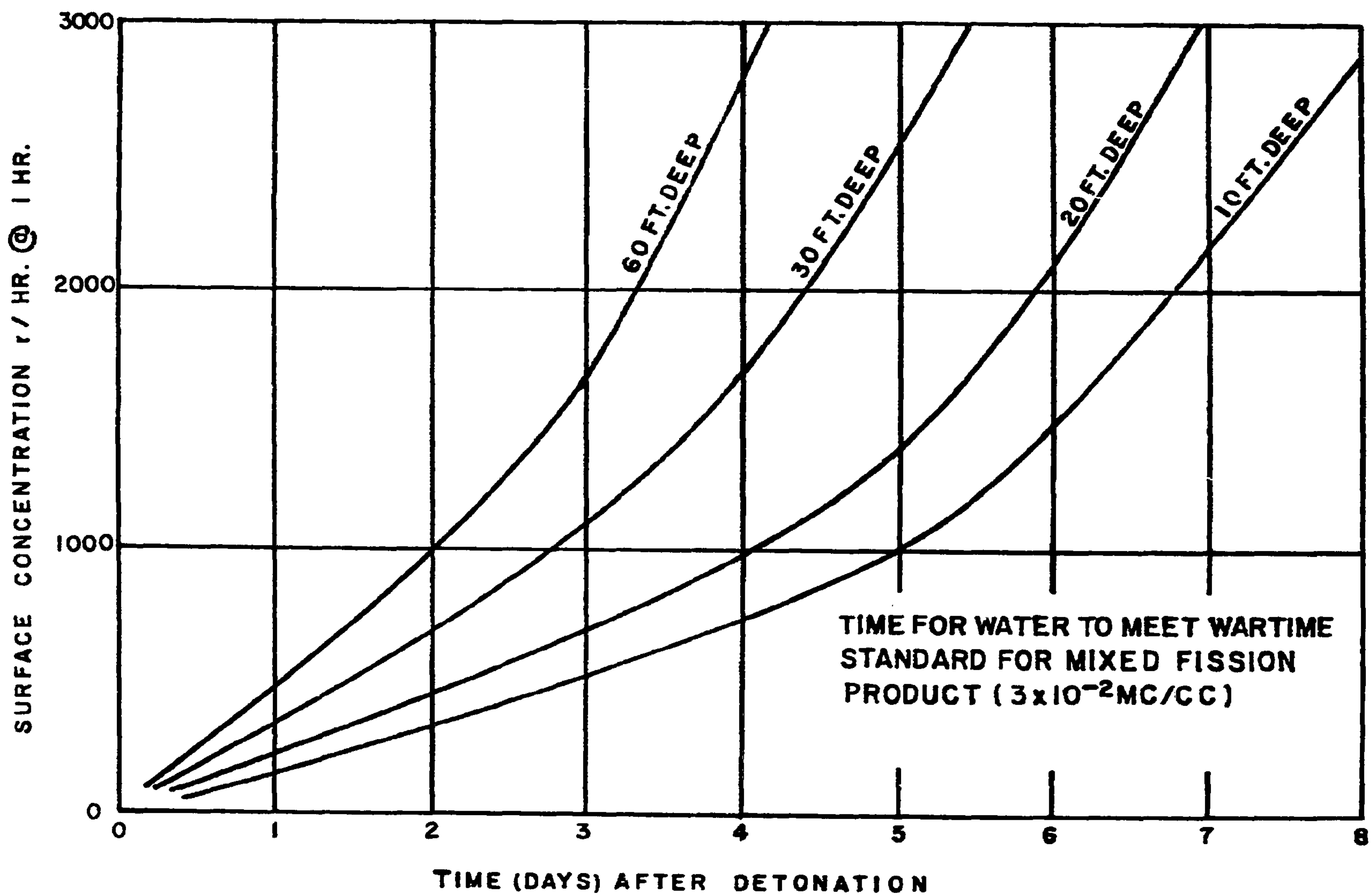
4.2.3 Effect of Type of Soil Upon Contamination

The rate of sedimentation of fallout in water is assumed to vary with the size of the soil particles. As a demonstration of the effect of the type of soil on contamination in a reservoir, the effects of clay-loam and sandy soil fallout were studied. In each case, 10 percent soluble fallout, having a radiation level of



CLAY-LOAM FALLOUT ON RESERVOIR-10% SOLUBLE, SEDIMENTATION ONLY.

FIGURE 4.13



CLAY-LOAM FALLOUT ON RESERVOIR–10% SOLUBLE–SEDIMENTATION ONLY.

FIGURE 4.14

3,000 r/hr. at 1 hour, was assumed to be deposited on an open reservoir 30 feet deep. The results, shown in Figure 4.15, indicate a consistently lower contamination due to the sandy soil fallout. This is due to the fact that the larger sand particles settle to the bottom more rapidly. However, the difference in contamination is not overly significant when compared with the other uncertain accuracies of the assumed parameters. Further discussion will, therefore, be limited to the consideration of clay-loam fallout, keeping in mind that other soils will produce slight variations in contamination.

4.3 THE EFFECT OF TREATMENT IN REDUCING CONTAMINATION (NO CONTRIBUTORY RUNOFF)

In order to determine the effect of treatment in reducing the degree of contamination, computations were made for the following assumed conditions:

a. Fallout directly on an open reservoir, 30 feet deep, with no contributory runoff.

b. Radiation levels of 100, 300, 1,500 and 3,000 r/hr. at 1 hour.

c. Clay-loam fallout - 10 percent soluble.

d. Treatment follows sedimentation in reservoir.

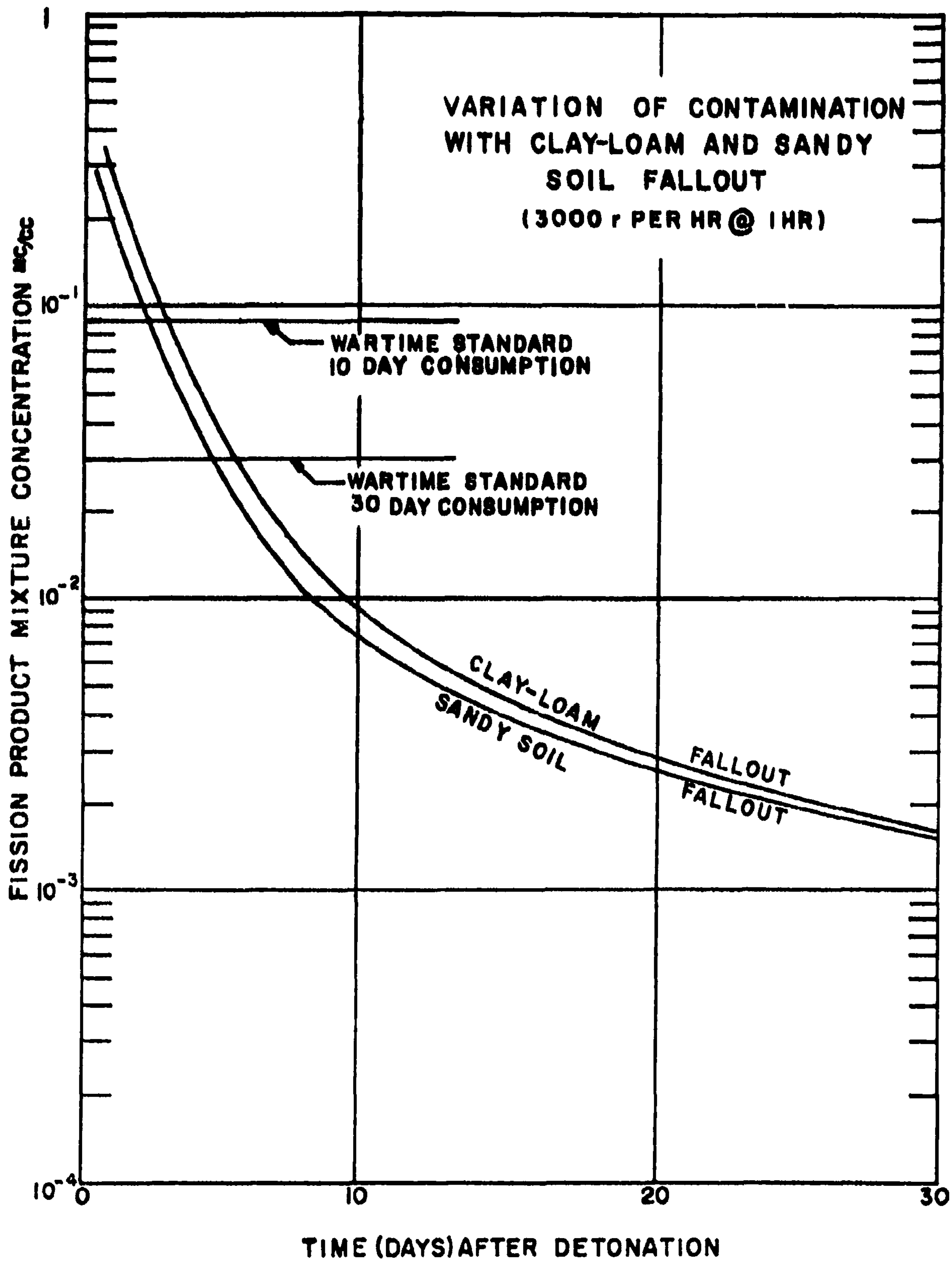
e. Treatment efficiencies for various processes are as follows:

(1) Alum coagulation and sand filtration removes 50 percent of soluble portion and 70 percent of insoluble portion.

(2) Lime soda-ash softening and sand filtration removes 66 percent of soluble portion and 78 percent of insoluble portion.

(3) Ion-exchange or distillation removes from 99.0 to 99.9 percent of the total contamination.

These, of course, are average values, but serve to illustrate the problem. A further discussion



CLAY-LOAM FALLOUT ON 30 FT. DEEP RESERVOIR 10% SOLUBLE.
SANDY SOIL FALLOUT ON 30 FT. DEEP RESERVOIR 10% SOLUBLE.

FIGURE 4.15

of treatment may be found in Section 5.

Computations were carried out as indicated in the following example.

EXAMPLE 4.4

An uncovered reservoir 30 feet deep is contaminated by fallout at a level of 3,000 r/hr. at 1 hour. The fallout is clay-loam and 10 percent soluble. Ten days after detonation the water is withdrawn from a point near the bottom of the reservoir and treated by the conventional alum coagulation and sand filtration process. Find the contamination after treatment.

Soluble Portion

Contamination before treatment = 6.4×10^{-3} MC/CC (Example 4.2)

Contamination after treatment = 6.4×10^{-3} MC/CC x (.50 remaining) = 3.2×10^{-3} MC/CC

Insoluble Portion

Contamination before treatment = 2.2×10^{-3} MC/CC (Example 4.2)

Contamination after treatment = 2.2×10^{-3} MC/CC x (.30 remaining) = 6.6×10^{-4} MC/CC

Total

Total contamination after treatment

$$= 3.2 \times 10^{-3} \text{ MC/CC} + 6.6 \times 10^{-4} \text{ MC/CC}$$
$$= 3.86 \times 10^{-3} \text{ MC/CC}$$

This includes a reduction in contamination due to dilution, sedimentation, radioactive decay and treatment which are functions of reservoir depth, type of fallout, time after detonation and nature of treatment. The effect of variation in radiation intensity was computed as indicated in Example 4.3. The results of these studies are given in Figures 4.16 through 4.23.

Figure 4.16 indicates contamination vs. time after conventional alum coagulation and sand filtration for various fallout levels. Wartime emergency standards for short duration consumption after such treatment are apparently surpassed within a few days. However, only water subjected to very low fallout levels would be suitable for extended peacetime consumption.

Figure 4.17 shows that lime soda-ash softening is slightly more efficient than alum coagulation.

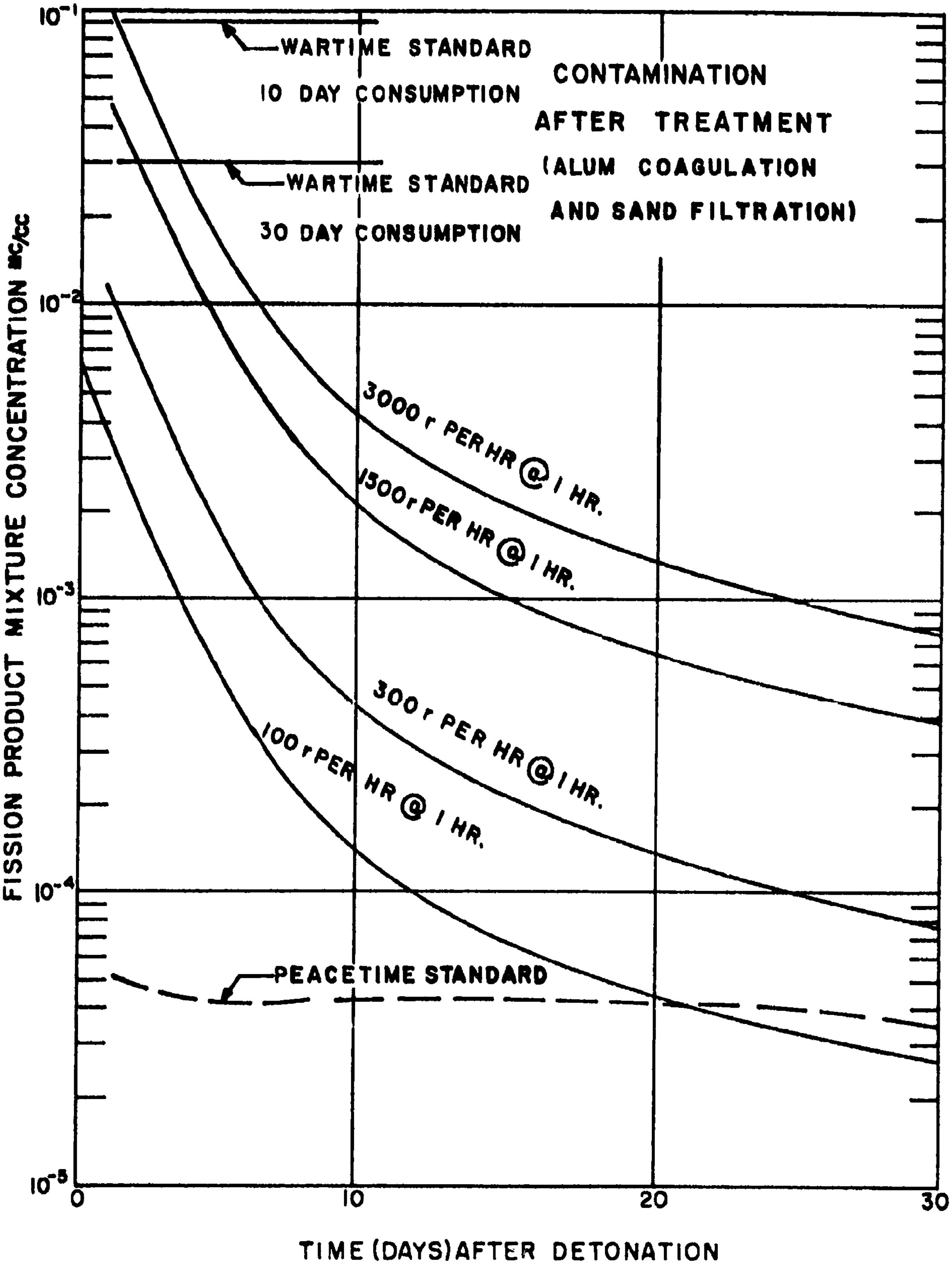
In general, however, these two conventional treatment processes cannot be depended upon to provide potable water except for a short emergency period.

Figures 4.18 and 4.19 demonstrate the effect of treatment using nuclear grade ion-exchange resins or distillation.

Figure 4.18 is based on 99.0 percent removal for either process, and Figure 4.19 assumes 99.9 percent removal. In some cases, removal in excess of 99.9 percent has been achieved using distillation. However, these are special treatment processes not ordinarily found in conventional water purification plants.

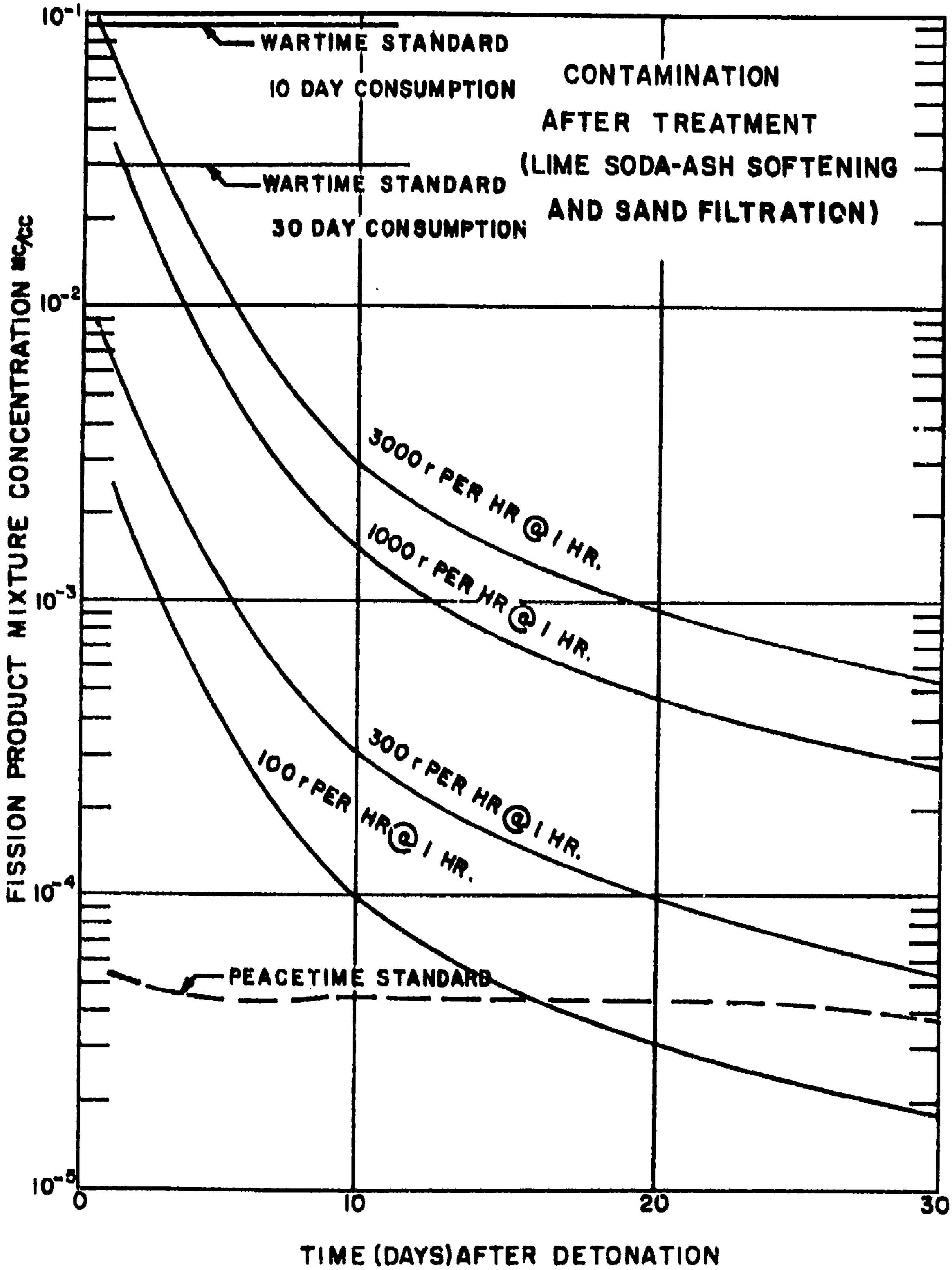
Figure 4.20 summarizes the effectiveness of various treatment processes using an arbitrarily selected fallout intensity of 3,000 r/hr. at 1 hour. It is evident from Figure 4.20 that special treatment such as ion-exchange or distillation is required to reduce grossly contaminated water to peacetime standards.

Figures 4.21 through 4.23 indicate the time after detonation that water subjected to various fallout concentrations would meet wartime or peacetime standards after receiving treatment. As an illustration in the use of these curves, assume an open reservoir is subject to a fallout intensity of 2,000 r/hr. at 1 hour. After



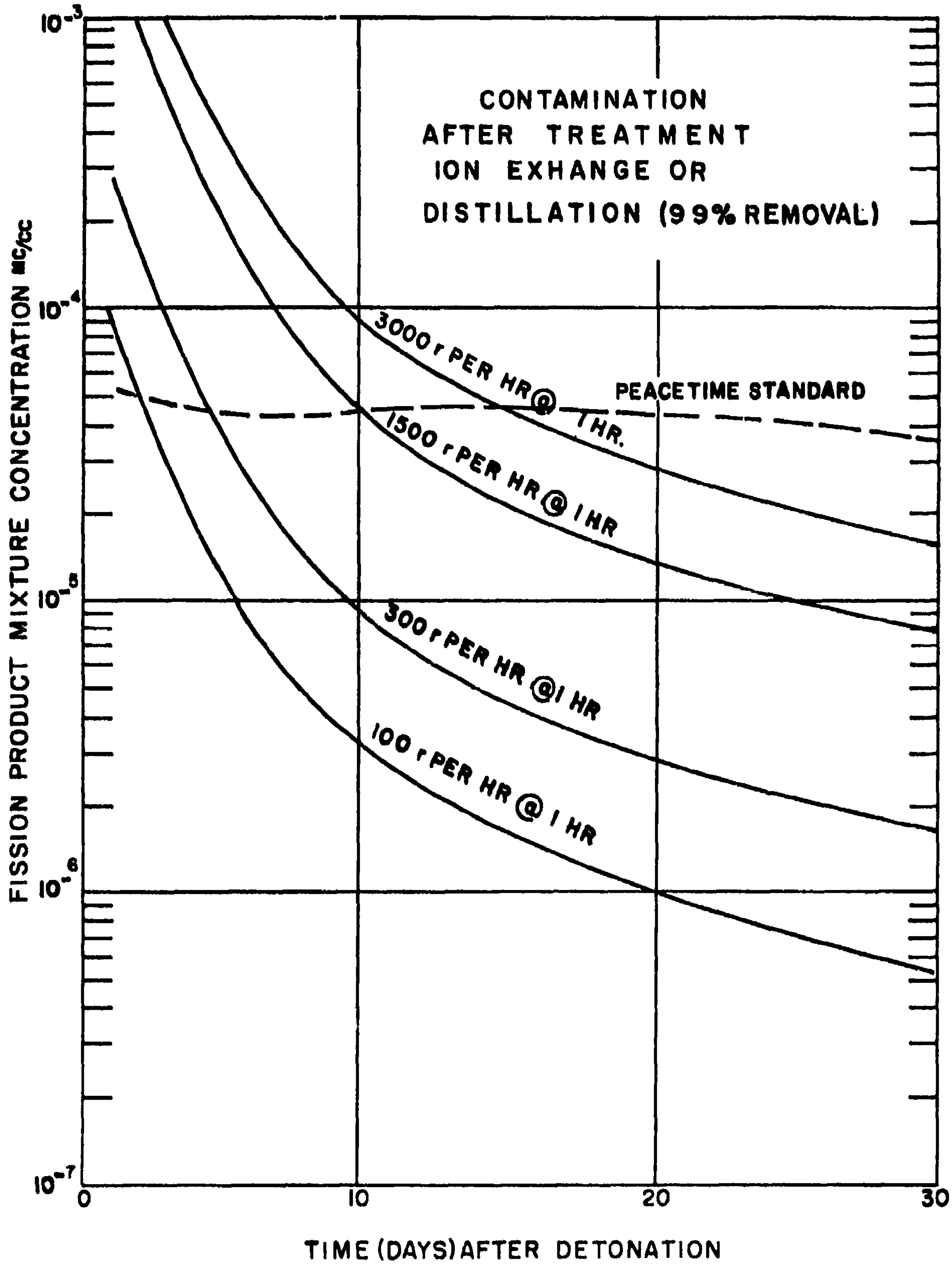
CLAY-LOAM FALLOUT ON 30 FT. DEEP RESERVOIR-10% SOLUBLE

FIGURE 4.16



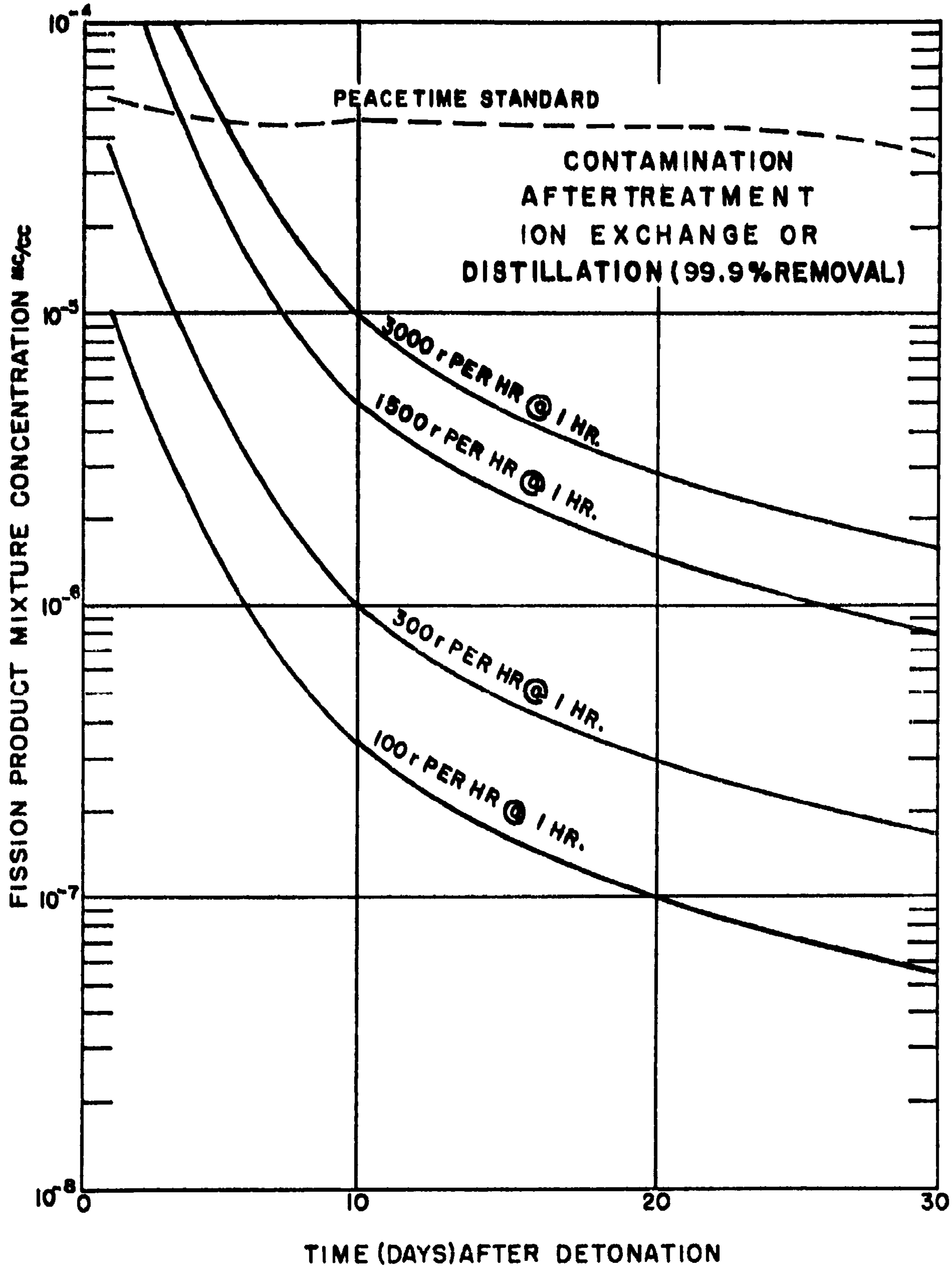
CLAY-LOAM FALLOUT ON 30 FT. DEEP RESERVOIR-10% SOLUBLE

FIGURE 4.17



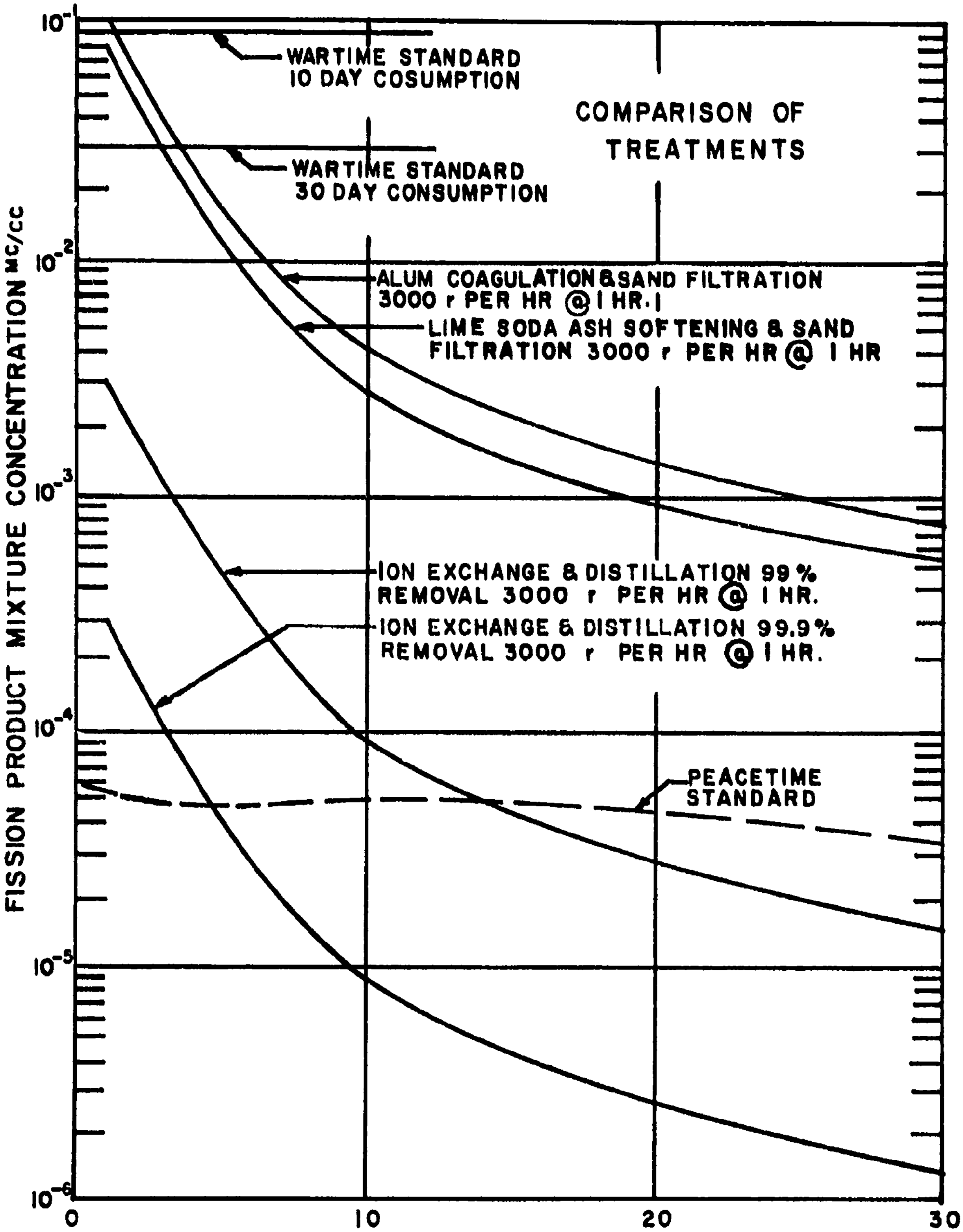
CLAY-LOAM FALLOUT ON 30 FT. DEEP RESERVOIR-10% SOLUBLE

FIGURE 4.18



CLAY-LOAM FALLOUT ON 30 FT. DEEP RESERVOIR-10% SOLUBLE.

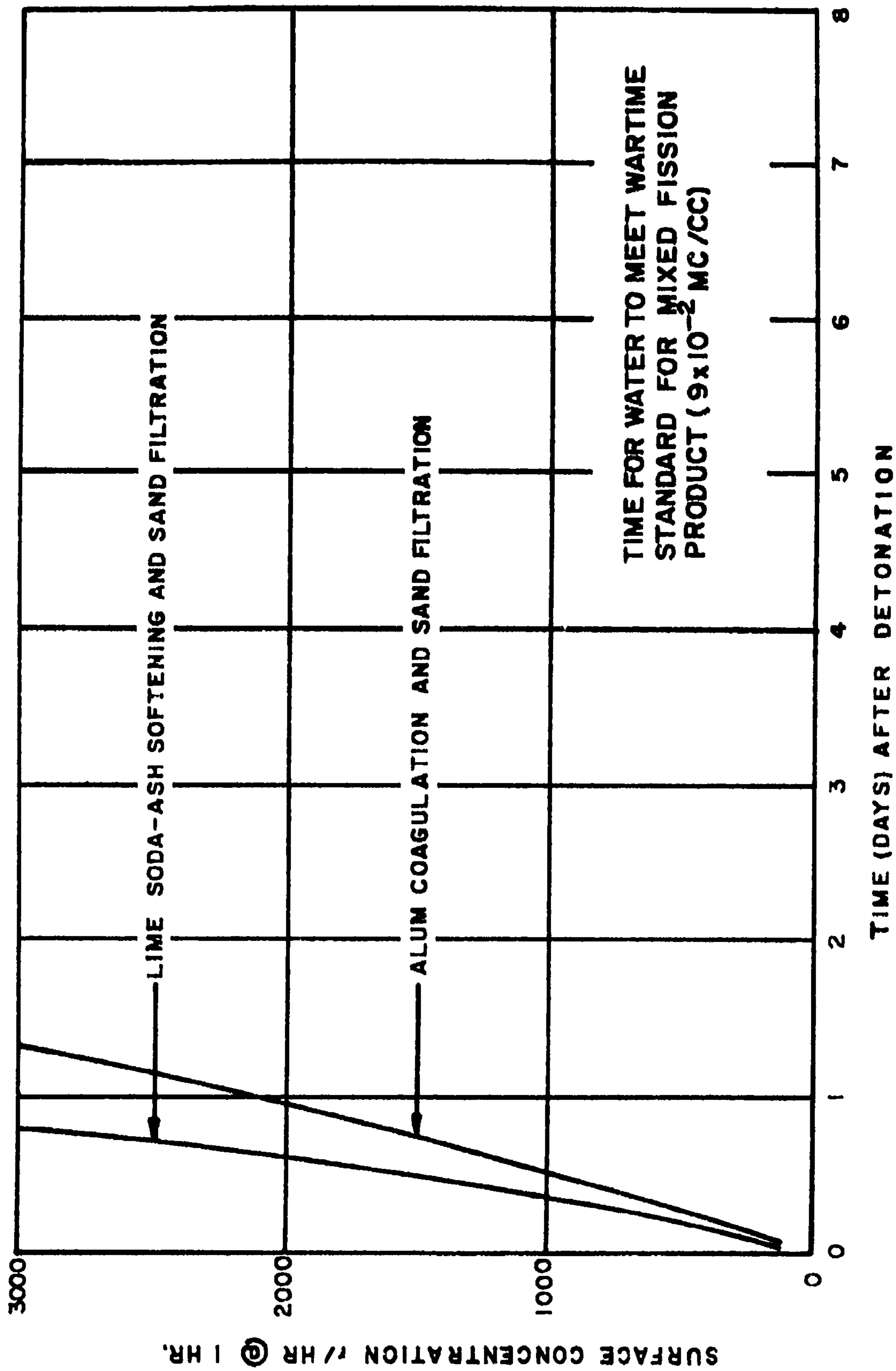
FIGURE 4.19



TIME (DAYS) AFTER DETONATION

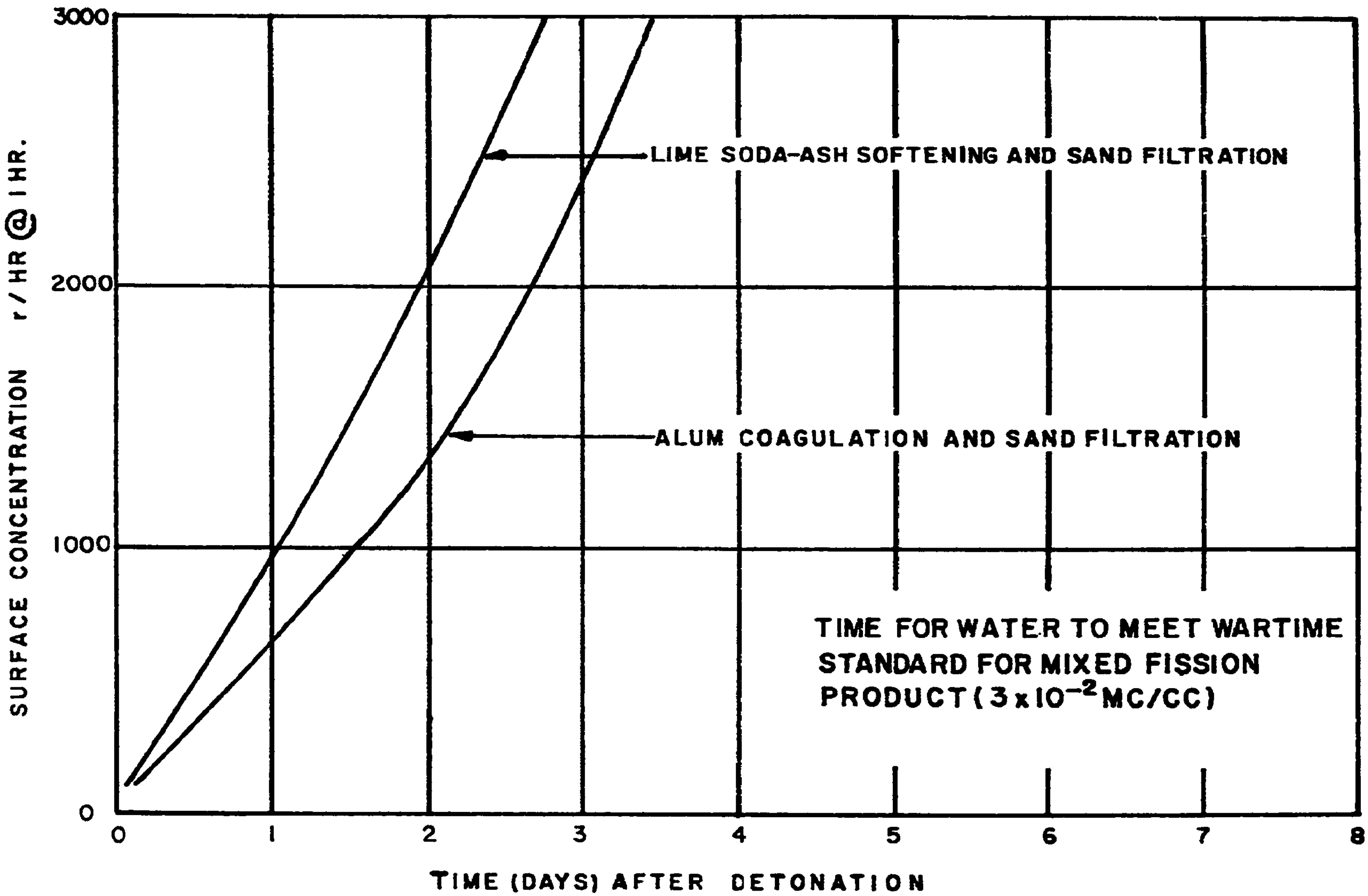
CLAY-LOAM FALLOUT ON 30 FT. DEEP RESERVOIR-10% SOLUBLE

FIGURE 4.20



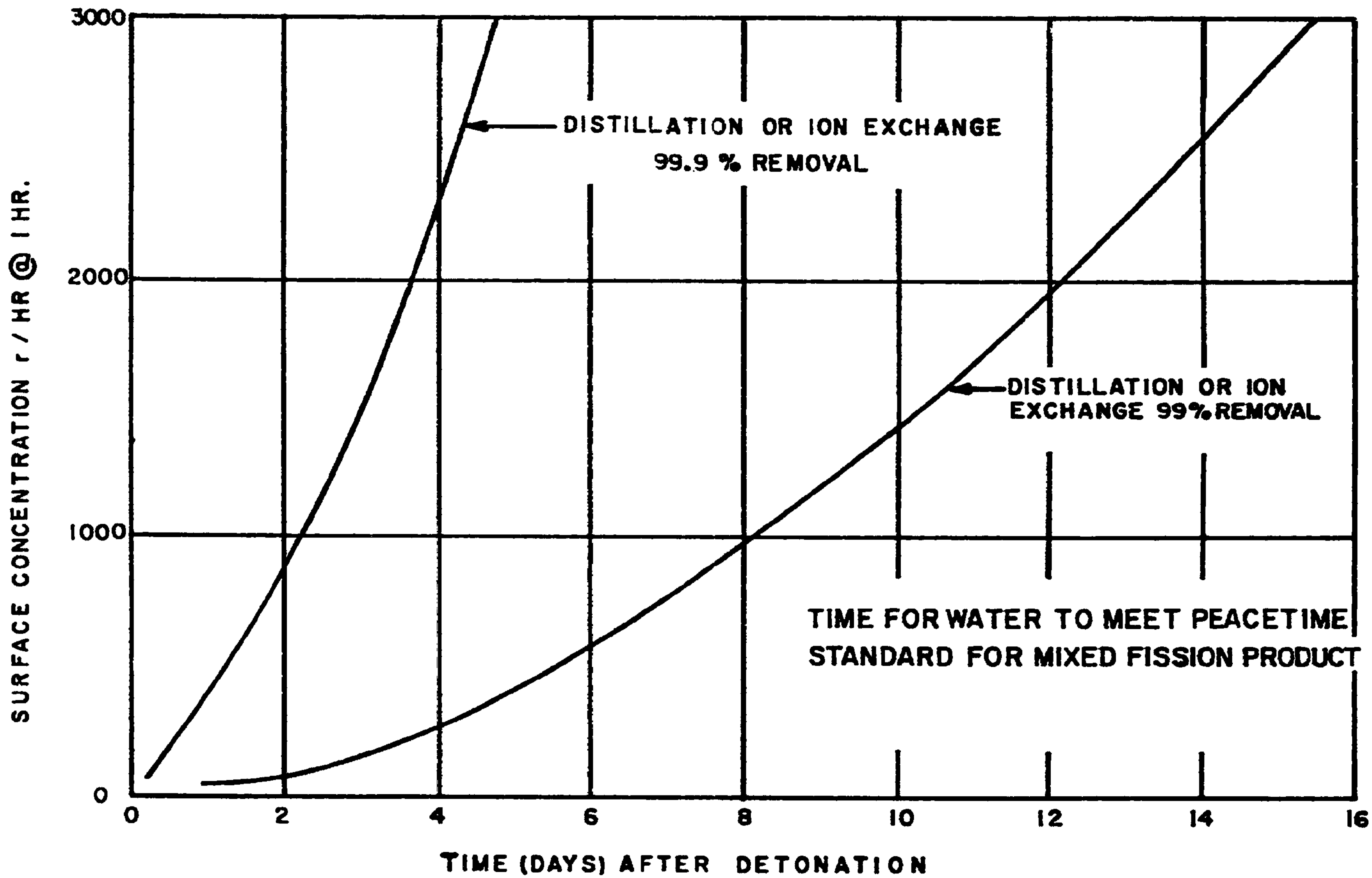
CLAY-LOAM FALLOUT ON 30 FT. DEEP RESERVOIR - 10% SOLUBLE.

FIGURE 4.21



CLAY-LOAM FALLOUT ON 30 FT. DEEP RESERVOIR–10% SOLUBLE.

FIGURE 4.22



CLAY-LOAM FALLOUT ON 30 FT. DEEP RESERVOIR–10% SOLUBLE

FIGURE 4.23

two days of sedimentation in the reservoir and subsequent treatment by a lime soda-ash softening process, the water near the bottom shows a contamination of 3.0×10^{-2} MC/CC (wartime standard for 30 days consumption).

It should be noted that conventional treatment (lime soda-ash or alum coagulation) will aid in meeting wartime emergency standards, but special treatment such as ion-exchange or distillation is required to meet peacetime standards.

4.4 FALLOUT ON LAND AND WATER AREAS

The contamination of water due to fallout occurring on land areas as well as directly on water areas is considered in this section. When the rate of precipitation exceeds the infiltration capacity of the soil, the excess water (surface runoff) will carry a portion of the fallout deposited on the earth's surface into streams and ultimately to rivers and reservoirs. The amount of runoff will have an effect on the quantity of fallout carried to the reservoir and, of course, on dilution. The prediction of runoff on a frequency basis is possible for individual drainage areas but requires a detailed analysis of precipitation records and the physical characteristics of the drainage basin. In this report, contamination is computed for various quantities of runoff (in inches of depth over the drainage area) without regard to the frequency of occurrence.

4.4.1 Method of Computing Contamination

In order to evaluate the contamination due to soluble and insoluble fallout on both land and water areas, the following relationships were developed.

$$C_S = \frac{V_2 \frac{(S f_1 f_2)}{R} + V_1 \frac{(S f_1 f_2)}{D}}{V_2 + V_1} \qquad \text{(Equation 4.1)}$$

$$C_I = \frac{V_2 \frac{(S f_3 f_4)}{R} + V_1 \; (I)}{V_2 + V_1} \qquad \text{(Equation 4.2)}$$

$$C_T = C_S + C_I \qquad \text{(Equation 4.3)}$$

Definition of terms in Equation 4.1, 4.2 and 4.3

C_S = Contamination due to soluble fallout (fissions/cu. ft.) or MC/CC

C_I = Contamination due to insoluble fallout (fissions/cu. ft.) or MC/CC

C_T = Total contamination (fissions/cu. ft.) or MC/CC

A_2 = Drainage or watershed area - sq. ft.

A_1 = Reservoir surface area - sq. ft.

V_2 = Volume of runoff - cu. ft.

V_1 = Volume of Water in reservoir - cu. ft.

R = Runoff in ft.

D = Depth of reservoir in ft.

S = Surface radiation in fissions/sq. ft. or r/hr. at 1 hour

I = Contamination in reservoir due to insoluble fallout deposited directly on reservoir - includes the effect of sedimentation

d = Days after detonation

f_1 = Factor of fallout which is soluble

f_2 = Factor of soluble fallout which appears in runoff

f_3 = Factor of fallout which is insoluble

f_4 = Factor of insoluble fallout which appears in runoff.

The first term appearing in parenthesis in Equation 4.1 is the contamination of runoff due to the soluble fallout, and the term in the second parenthesis is the contamination of the reservoir water due to the soluble fallout. Similarly, the parenthesized terms in Equation 4.2 indicate the contamination of runoff and reservoir water due to the insoluble portion of fallout.

It should be noted that factors f_2 and f_4 represent the amounts of soluble and insoluble amounts of radiation respectively which actually appear in runoff contributing to reservoir contamination. The actual valves are dependent upon a number of factors which include ion exchange, particle filtration and sedimentation, etc. The valves used herein are for comparison purposes and have been arbitrarily selected.

The following example demonstrates the use of these equations.

EXAMPLE 4.5

Fallout having an intensity of 3,000 r/hr. at 1 hour occurs on an open reservoir 30 feet deep as well as on the entire watershed area. Determine the degree of contamination 10 days after detonation for the following conditions:

$A_2/A_1 = \frac{\text{Watershed Area}}{\text{Reservoir Surface Area}} = 100$

$R = \text{Runoff} = \frac{3 \text{ inches}}{12 \text{ in./ft.}} = 0.25 \text{ ft.}$

f_1 = Factor soluble = 0.10 or 10 percent

f_2 = Factor soluble appearing in runoff = 0.10 or 10 percent

f_3 = Factor insoluble = 0.90 or 90 percent

f_4 = Factor insoluble appearing in runoff = 0.03 or 3 percent

Note: The fallout is 10 percent soluble and 90 percent insoluble. The 3 inches of runoff carries 10 percent of the soluble portion and 3 percent of the insoluble portion into the reservoir.

Solution -

Surface radiation $= 6 \times 10^{15} \frac{\text{fissions}}{\text{sq. ft.}}$ (3,000 r/hr. at 1 hr.)

$$Cs = \frac{(S\, f_1\, f_2)\left(\frac{A_2}{A_1} + 1\right)}{\frac{A_2}{A_1}(R) + D} \quad \text{(From Equation 4.1)}$$

$$C_s = \frac{\left(6 \times 10^{15} \frac{\text{fission}}{\text{ft}^2} \times .10 \times .10\right)(100 + 1)}{100\,(0.25)\text{ ft.} + 30\text{ ft.}}$$

$$= 1.1 \times 10^{14} \text{ fission/ft.}^3$$

$$C_s = 1.1 \times 10^{14} \frac{\text{fission}}{\text{ft}^3} \times \frac{9.0 \times 10^{-4}\text{ MC}}{10^8 \text{ fission}} \times 3.54$$

$$\times \frac{10^{-5}\text{ ft}^3}{\text{CC}} = 3.50 \times 10^{-2} \frac{\text{MC}}{\text{CC}}$$

$$C_I = \frac{\frac{A_2}{A_1}(S \times f_3 \times f_4) + D(I)}{\frac{A_2}{A_1} R + D} \quad \text{(From Equation 4.2)}$$

$$C_I = \frac{100\,(6 \times 10^{15} \times .90 \times .03) + 30\,(7 \times 10^{12})}{100\,(.25) + 30}$$

$$= 2.98 \times 10^{14} \frac{\text{fission}}{\text{ft}^3}$$

$$C_I = 2.98 \times 10^{14} \frac{\text{fission}}{\text{ft}^3} \times \frac{9.0 \times 10^{-4}\text{ MC}}{10^8 \text{ fission}} \times 3.54$$

$$\times 10^{-5} \frac{\text{ft}^3}{\text{CC}} = 9.45 \times 10^{-2} \frac{\text{MC}}{\text{CC}}$$

$$C_T = C_S + C_I = 3.50 \times 10^{-2} + 9.45 \times 10^{-2}$$

$$= 1.30 \times 10^{-1} \frac{\text{MC}}{\text{CC}}$$

In order to determine the effect of various parameters on contamination, a series of curves was constructed using the above procedure.

These curves are general in nature and are intended to serve the following functions:

a. Demonstrate a computational procedure that can be applied to individual water systems.

b. Assist in evaluating the relative importance of various parameters.

c. Define the range of possible contamination as an aid to pre-attack planning.

4.4.1.1 The Effect of Runoff and Area Ratio (A_2/A_1) on Contamination (Figures 4.24 through 4.27) - In order to determine the effect of runoff and area ratio on contamination, a series of computations were made holding the following values constant:

S = 3,000 r/hr. at 1 hour

D = Depth of reservoir = 30 feet

f_1 = 0.10

f_2 = 0.10

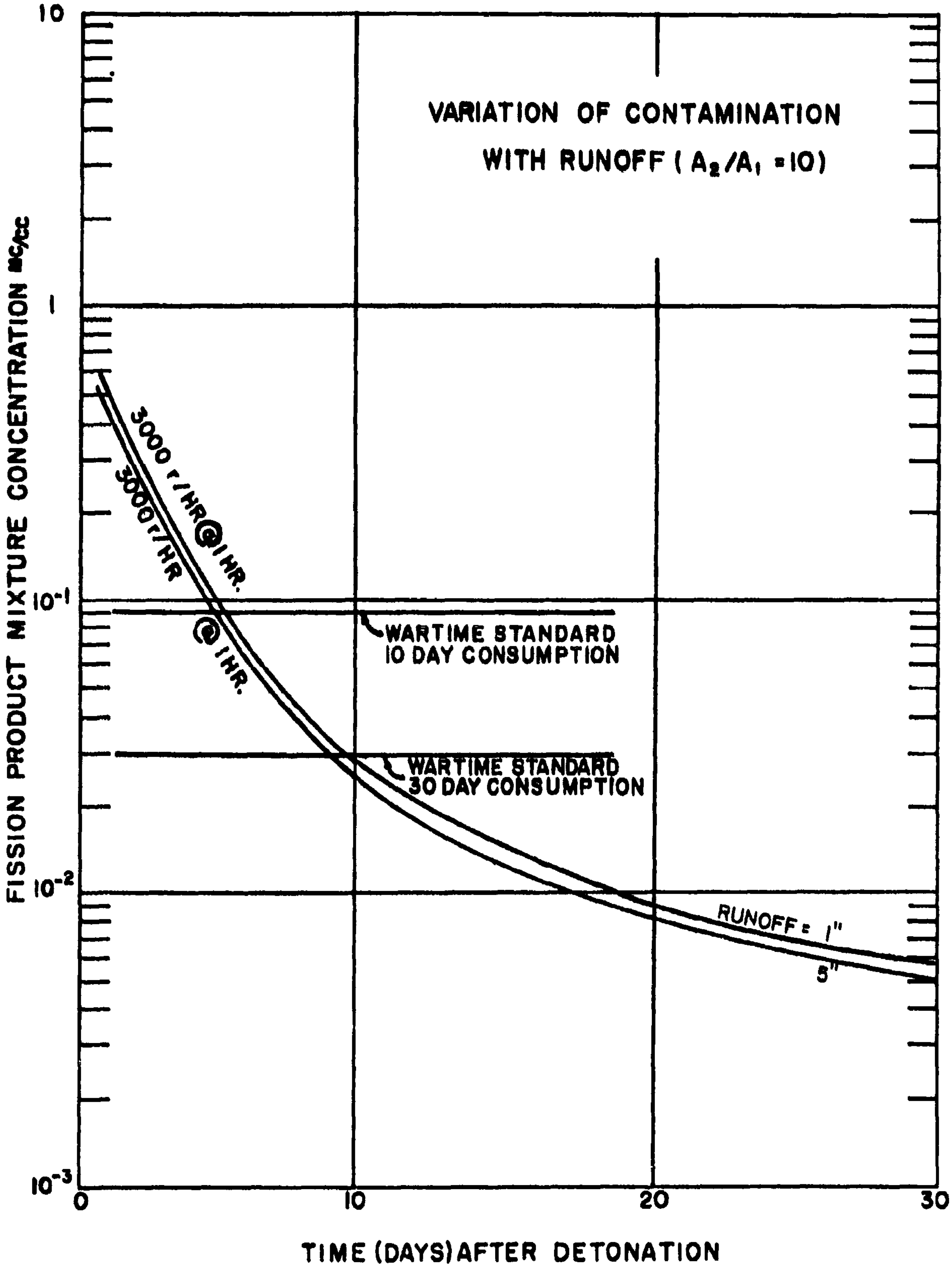
f_3 = 0.90

f_4 = 0.03

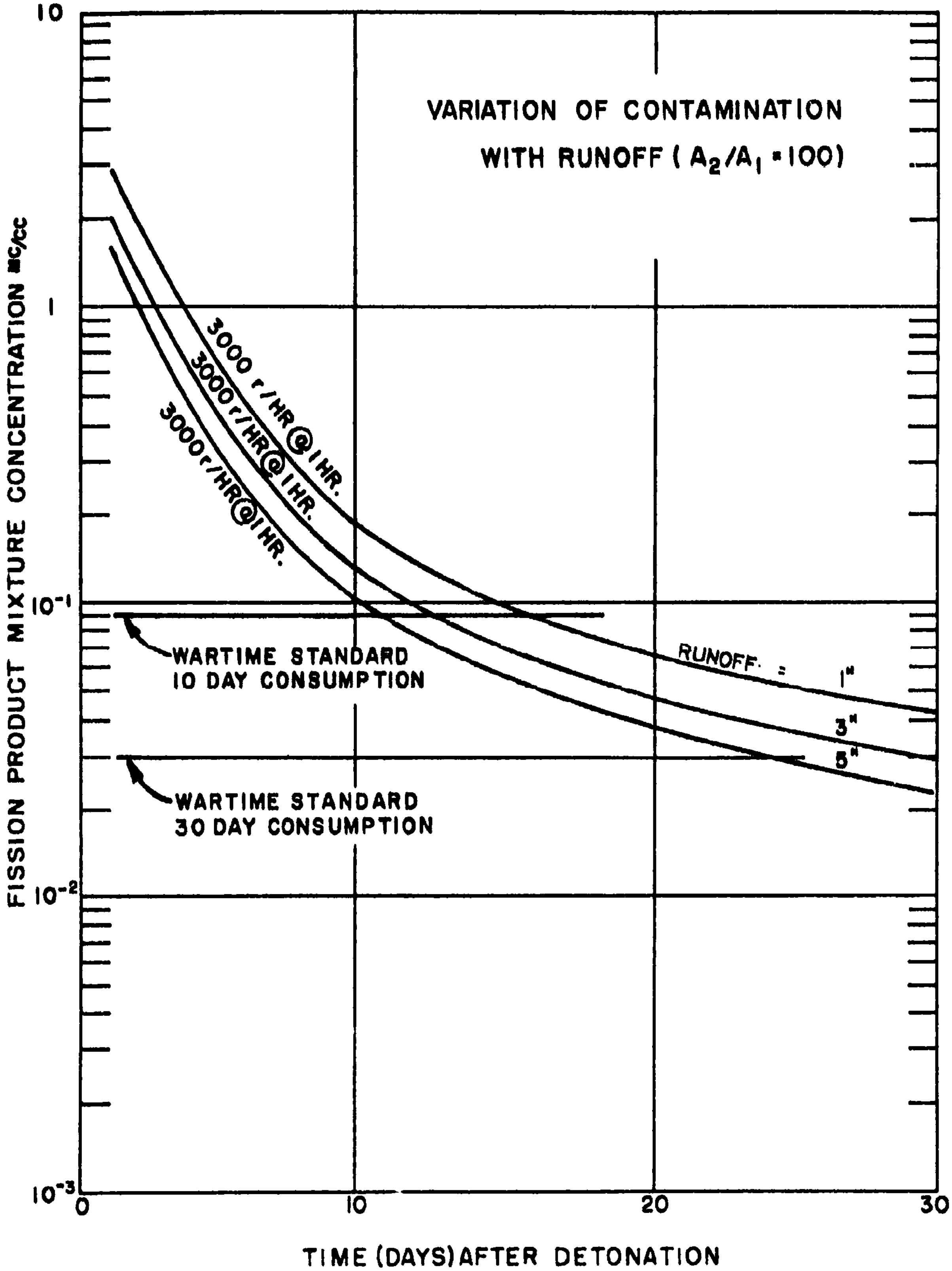
The contamination was computed for runoff values (R) of 1", 3" and 5" and for area ratios of 10; 100; 1,000; and 10,000. The ratio of watershed area to reservoir surface area is seen to have a pronounced effect on contamination. Large watershed areas contribute more fallout to the reservoir and result in greater contamination.

These curves also show that for any constant value of (A_2/A_1) the degree of contamination varies inversely with the depth of runoff. This is due principally to greater dilution of contamination in the higher runoffs. This trend might conceivably be reversed to some extent however, due to an increase in the amount of fallout (factors f_2 and f_4) carried into the reservoir by increased runoff.

4.4.1.2 The Effect of Runoff Factors on Contamination (Figures 4.28 through 4.30) - These curves indicate the degree of contamination for the following assumed conditions:

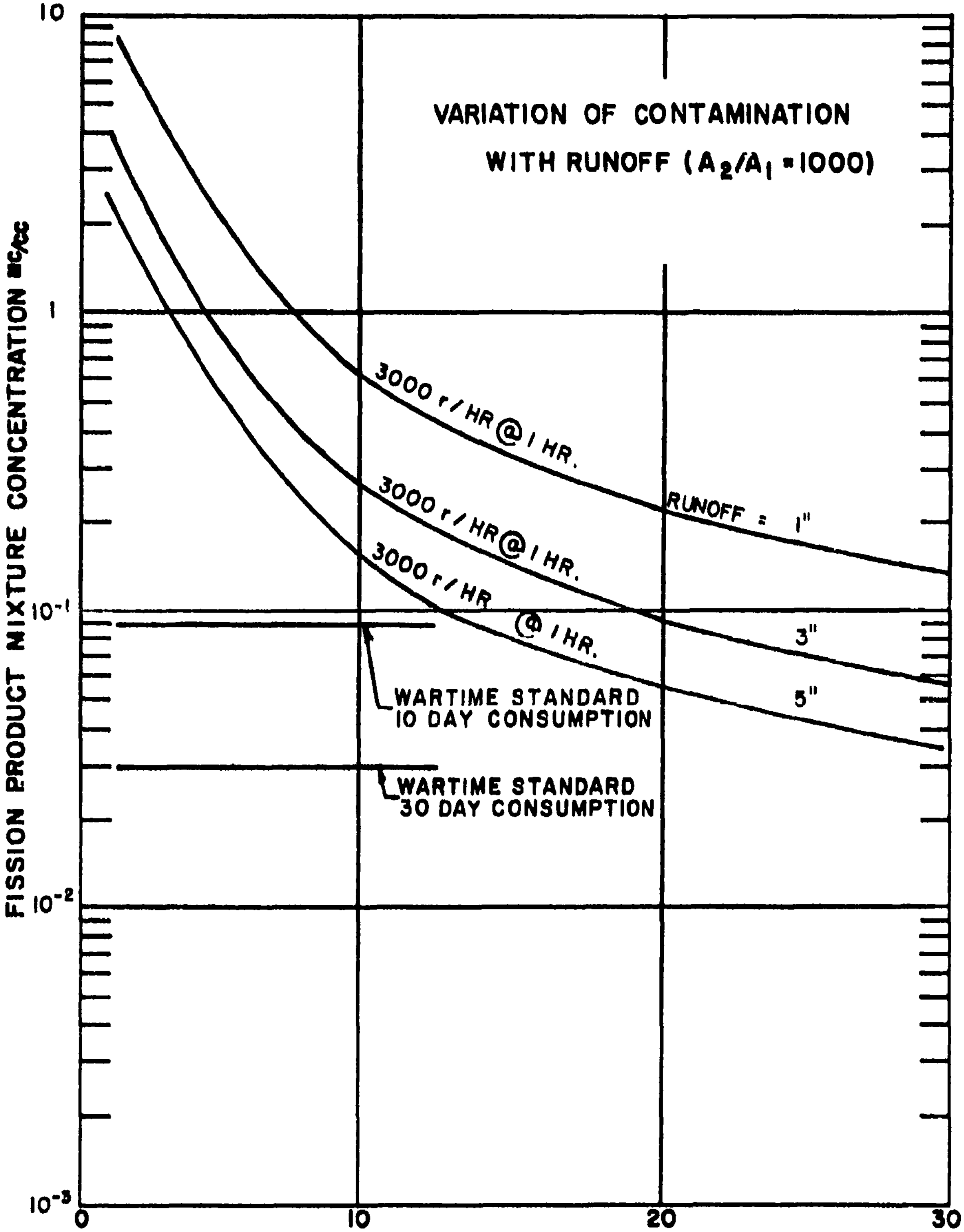


CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR
10% SOLUBLE
FALLOUT IN RUNOFF = 10% OF SOLUBLE, 3% OF INSOLUBLE
FIGURE 4.24

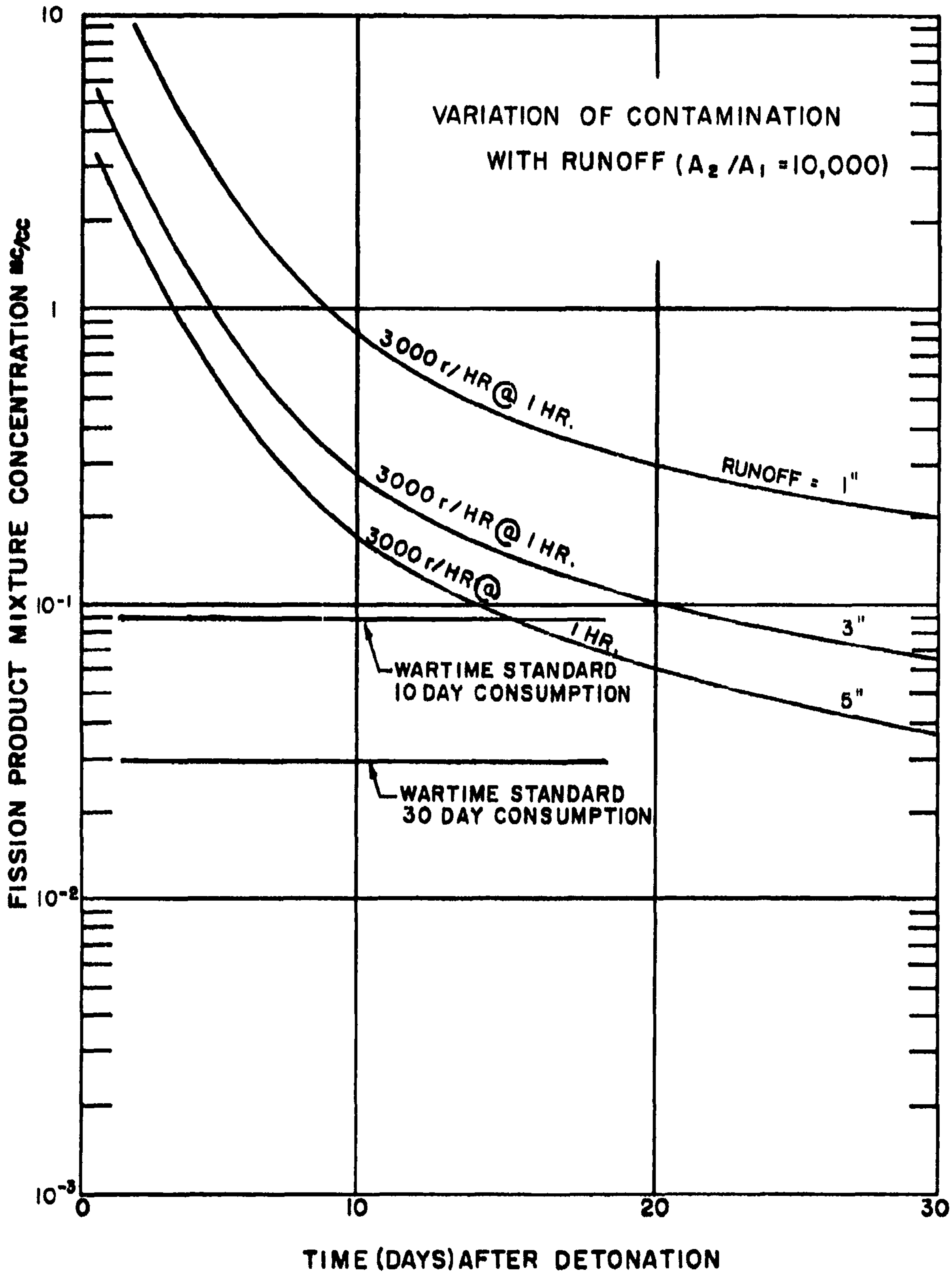


CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR
10% SOLUBLE
FALLOUT IN RUNOFF = 10% OF SOLUBLE, 3% OF INSOLUBLE

FIGURE 4.25

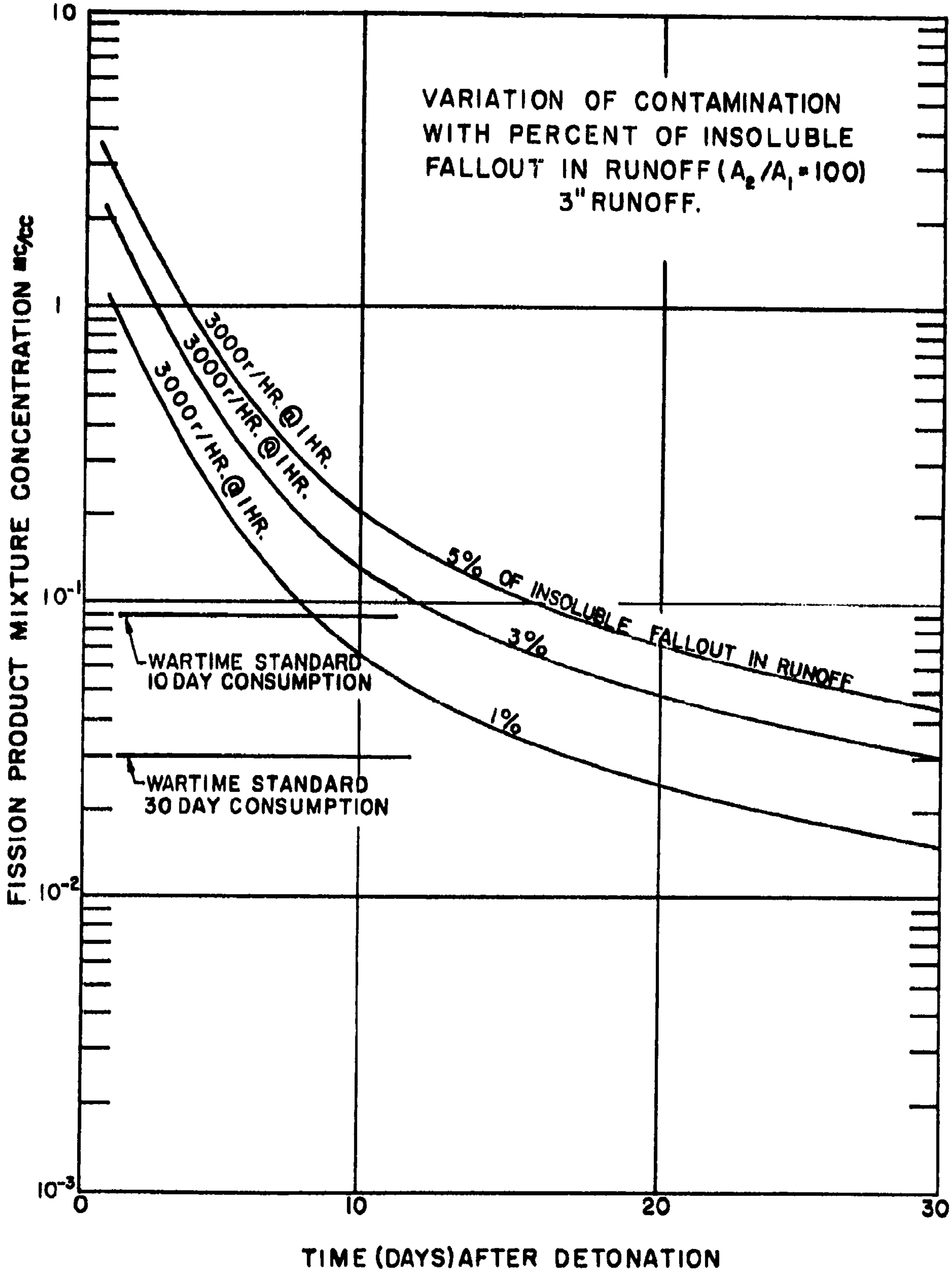


CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR
10% SOLUBLE
FALLOUT IN RUNOFF = 10% OF SOLUBLE, 3% OF INSOLUBLE
FIGURE 4.26



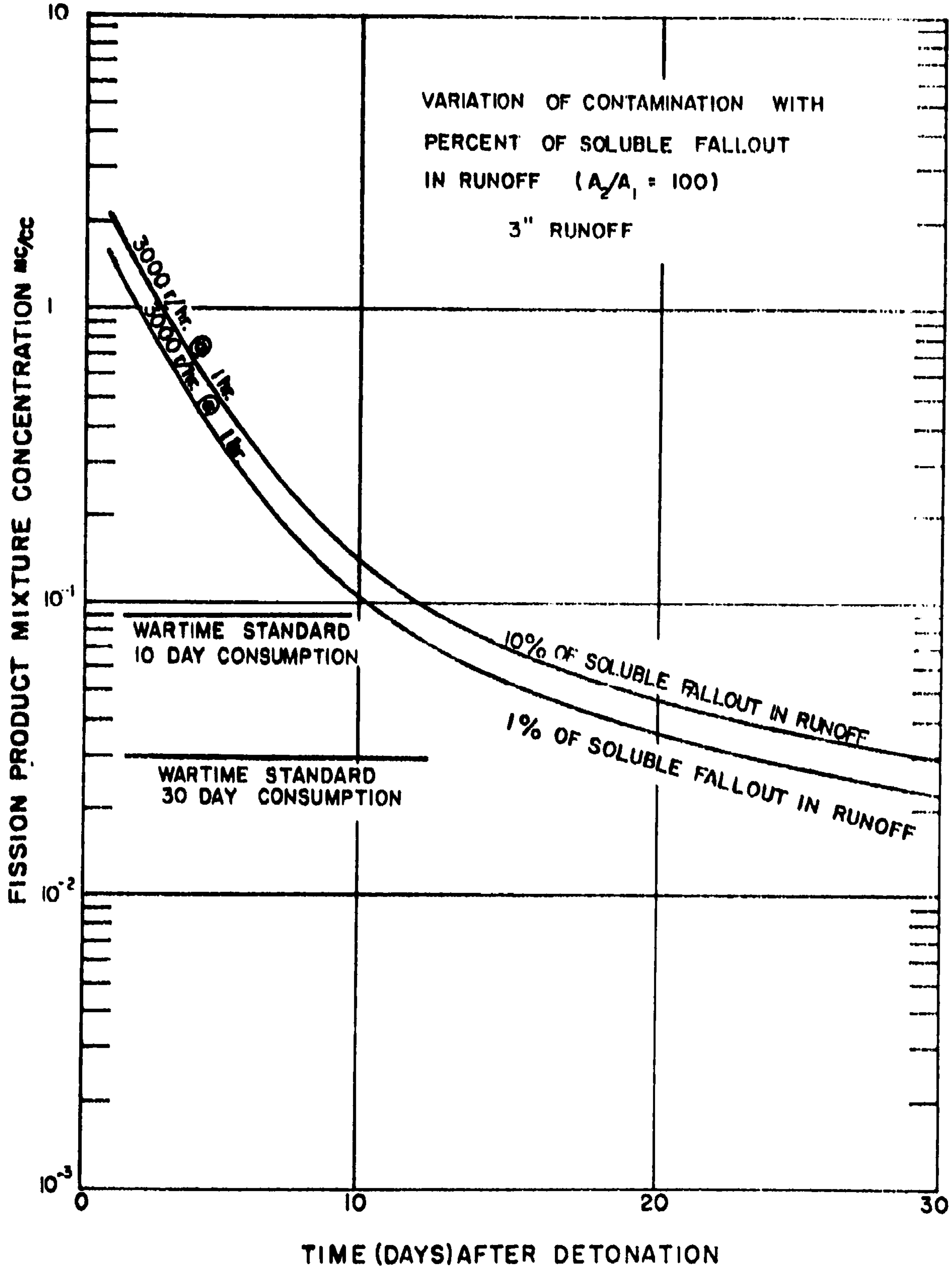
CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR
10 % SOLUBLE
FALLOUT IN RUNOFF = 10% OF SOLUBLE, 3% OF INSOLUBLE

FIGURE 4.27



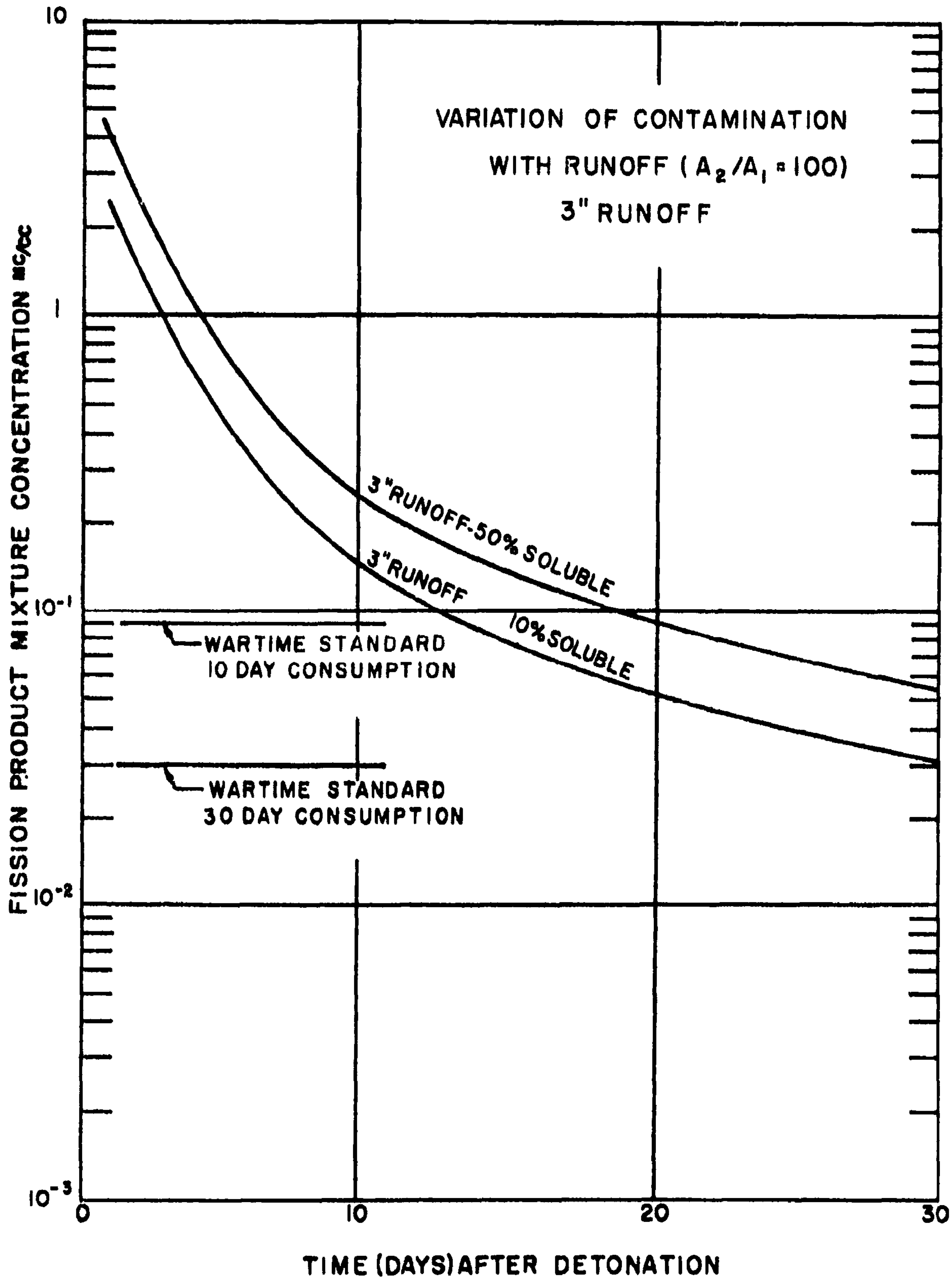
CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR
10% SOLUBLE
FALLOUT IN RUNOFF = 10% OF SOLUBLE, (1%, 3%, 5%) OF INSOLUBLE

FIGURE 4.28



CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT DEEP RESERVOIR
10% SOLUBLE
FALLOUT IN RUNOFF = 1 & 10% OF SOLUBLE, 3% OF INSOLUBLE

FIGURE 4.29



CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR

FALLOUT IN RUNOFF = 10% OF SOLUBLE, 3% OF INSOLUBLE

FIGURE 4.30

A_2/A_1 = 100

R (runoff) = 3"

S (Surface radiation) = 3,000 r/hr. at 1 hour

D (depth of reservoir) = 30 feet

Figure 4.28 indicates the effect upon contamination of a variation in runoff factor "f_4". Factors f_1, f_2 and f_3 are held constant at the following values:

f_1 = 0.10

f_2 = 0.10

f_3 = 0.90

f_4 = varies-0.01, 0.03 and 0.05

As the percentage of insoluble fallout carried into the reservoir with runoff increases, contamination increases to the extent indicated.

Figure 4.29 is similar to Figure 4.28 except that all runoff factors are held constant, except "f_2", to show the effect upon contamination of a variation in the soluble portion of fallout in runoff. Assumed factors are:

f_1 = 0.10

f_2 = 0.01 and 0.10

f_3 = 0.90

f_4 = 0.03

Figure 4.30 indicates variation of contamination with fallout solubility for the following assumed conditions:

f_1 = varies-0.10 to 0.50

f_2 = 0.10

f_3 = varies-0.90 to 0.50

f_4 = 0.03

Close-in fallout is estimated to be from 1 to 10 percent soluble and intermediate fallout 50 percent soluble. This figure shows the variation in contamination with solubility if all other factors are kept constant.

Figures 4.28, 4.29 and 4.30 indicate the general effect of factors f_1, f_2, f_3 and f_4 on contamination. While the conditions and ranges assumed here are subject to considerable variation, it can be seen that their overall effects upon contamination will remain relatively small compared with other parameters.

4.4.1.3 The Effect on Contamination of Surface Radiation and the Area Ratio A_2/A_1 (Figure 4.31) - This figure shows the large variation in contamination possible due to variations in surface radiation and area ratio. The upper curve indicates gross contamination for the following conditions:

S = Surface Radiation = 3,000 r/hr at 1 hr.

A_2/A_1 = Area Ratio = 10,000

R = Runoff = 1"

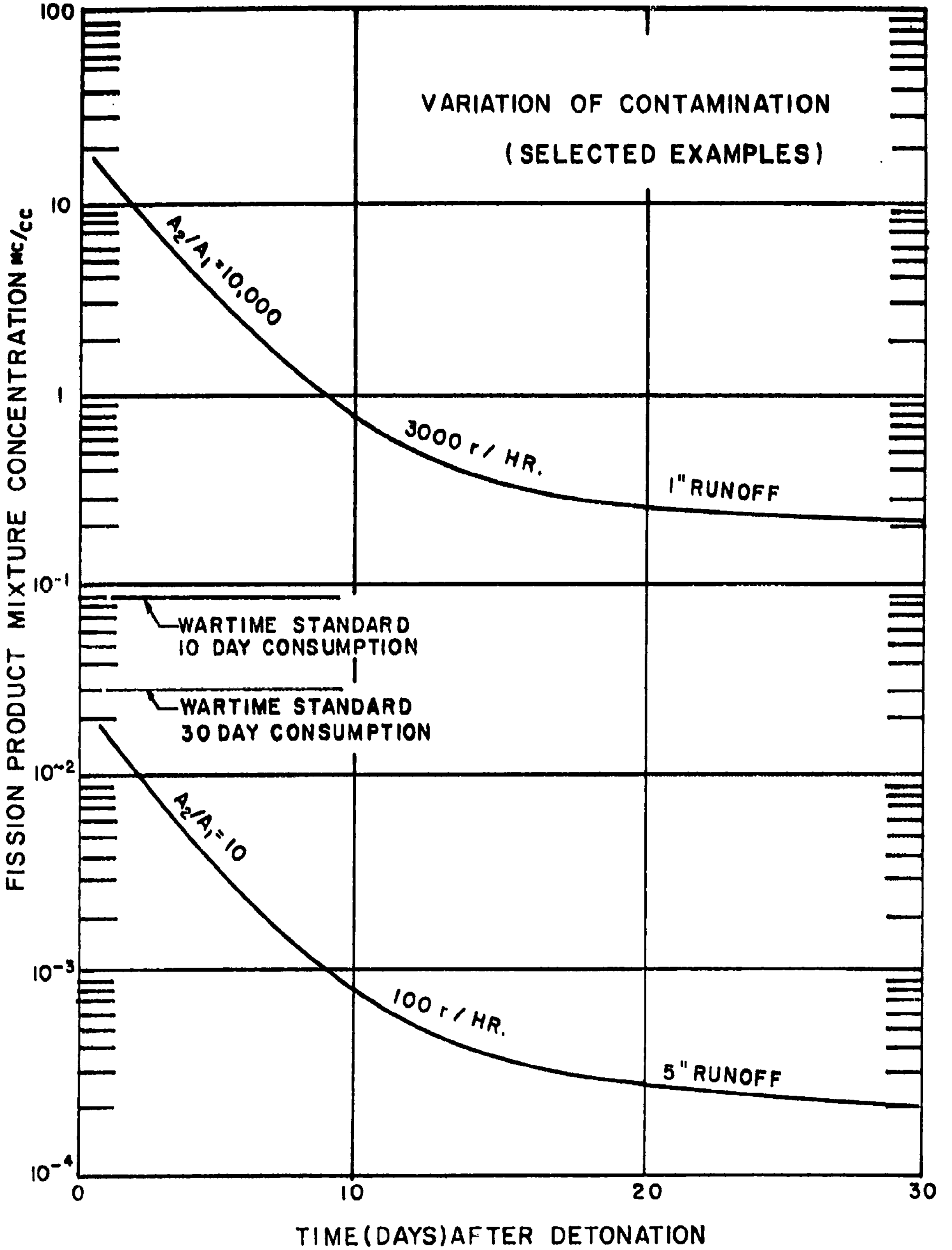
The lower curve indicates contamination for the following conditions:

S = 100 r/hr. at 1 hour

A_2/A_1 = 10

R = 5"

The two curves define a spectrum into which most water systems would fall for pre-attack planning purposes.



CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR
10% SOLUBLE
FALLOUT IN RUNOFF = 10% OF SOLUBLE, 3% OF INSOLUBLE

FIGURE 4.31

4.5 THE EFFECT OF TREATMENT ON CONTAMINATION (INCLUDING CONTRIBUTORY RUNOFF) - FIGURES 4.32 THRU 4.39

These curves indicate contamination for the following representative conditions.

Clay-loam fallout on drainage area and reservoir.

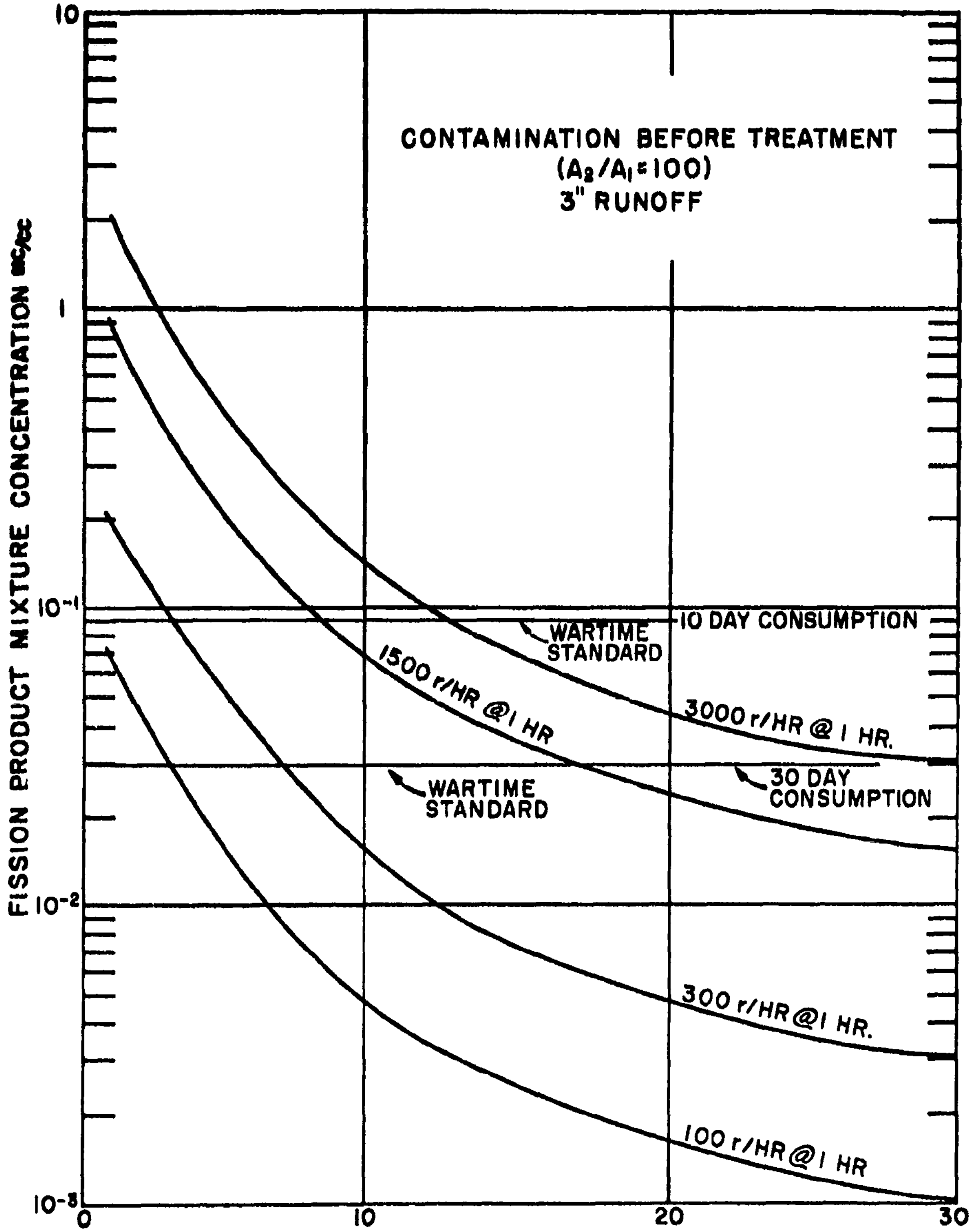
S	=	Surface radiation. Specific curves are drawn for intensities of 3,000; 1,500; 300 and 100 r/hr. at 1 hour.
D	=	Depth of reservoir = 30 feet
d	=	days after detonation (from 0 to 30)
A_2/A_1	=	Ratio of watershed area to reservoir area = 100
R	=	Runoff = 3 inches
f_1	=	Factor soluble = 0.10
f_2	=	Factor of soluble fallout in runoff = 0.10
f_3	=	Factor insoluble = 0.90
f_4	=	Factor of insoluble fallout in runoff = 0.03

4.5.1 Contamination Before Treatment

The variation of contamination with time for various fallout intensities and the above stated conditions are shown in Figure 4.32. Wartime and peacetime standards for potable water are superimposed for comparison.

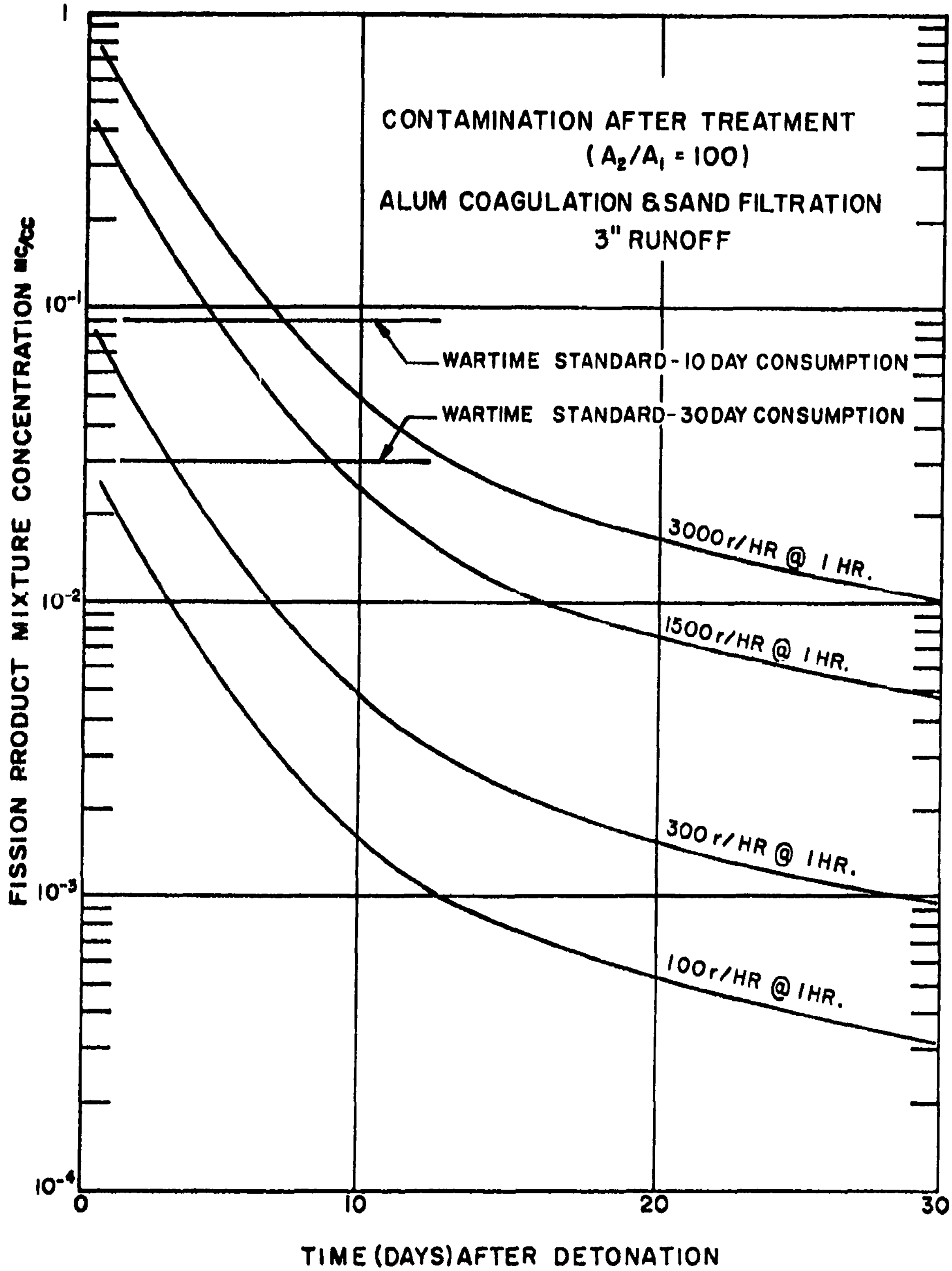
4.5.2 Contamination after Treatment

Figures 4.33 through 4.36 indicate the contamination remaining after treatment. Two conventional

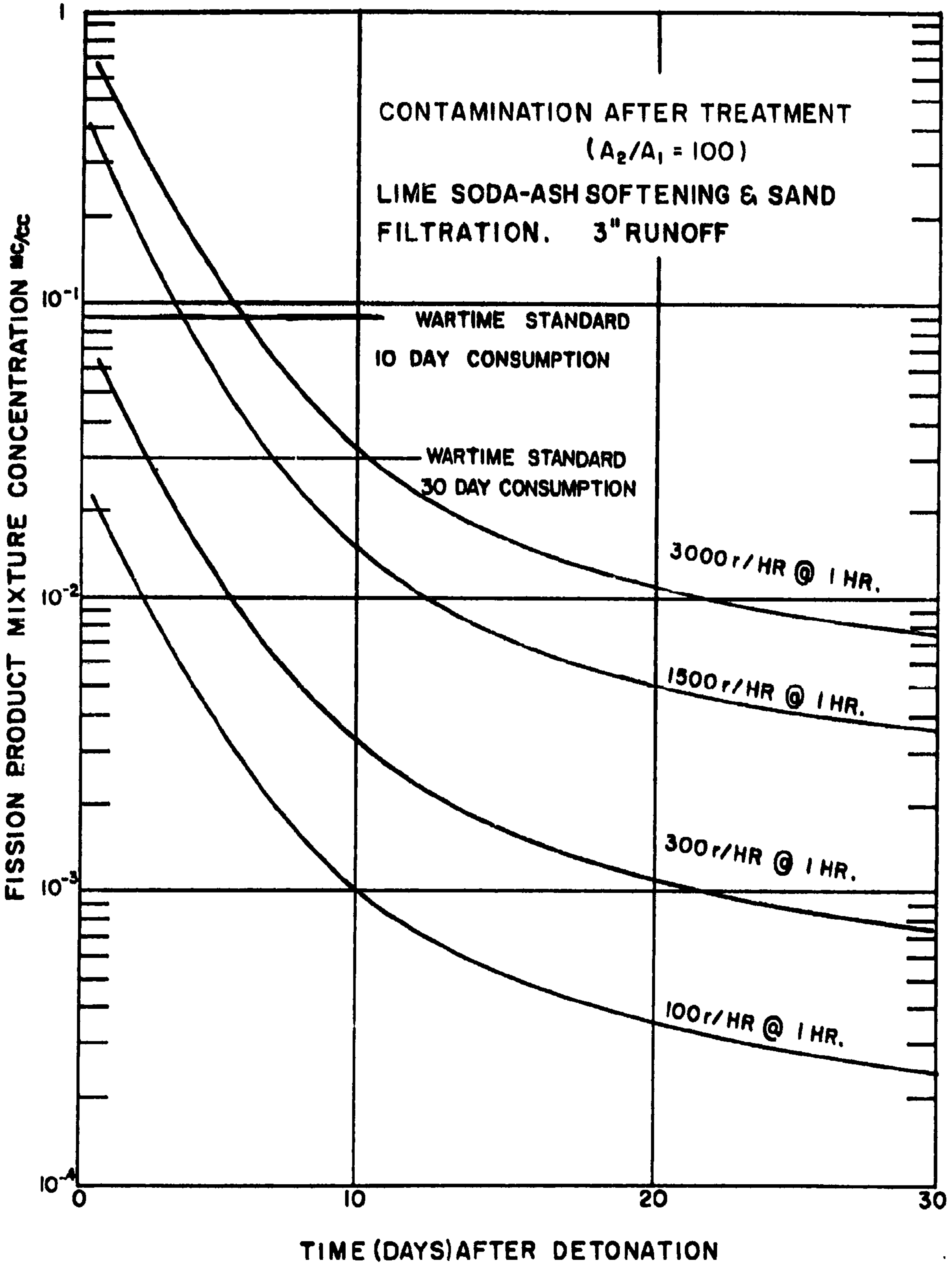


CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30FT DEEP RESERVOIR
10% SOLUBLE
FALLOUT IN RUNOFF = 10% OF SOLUBLE, 3% OF INSOLUBLE

FIGURE 4.32

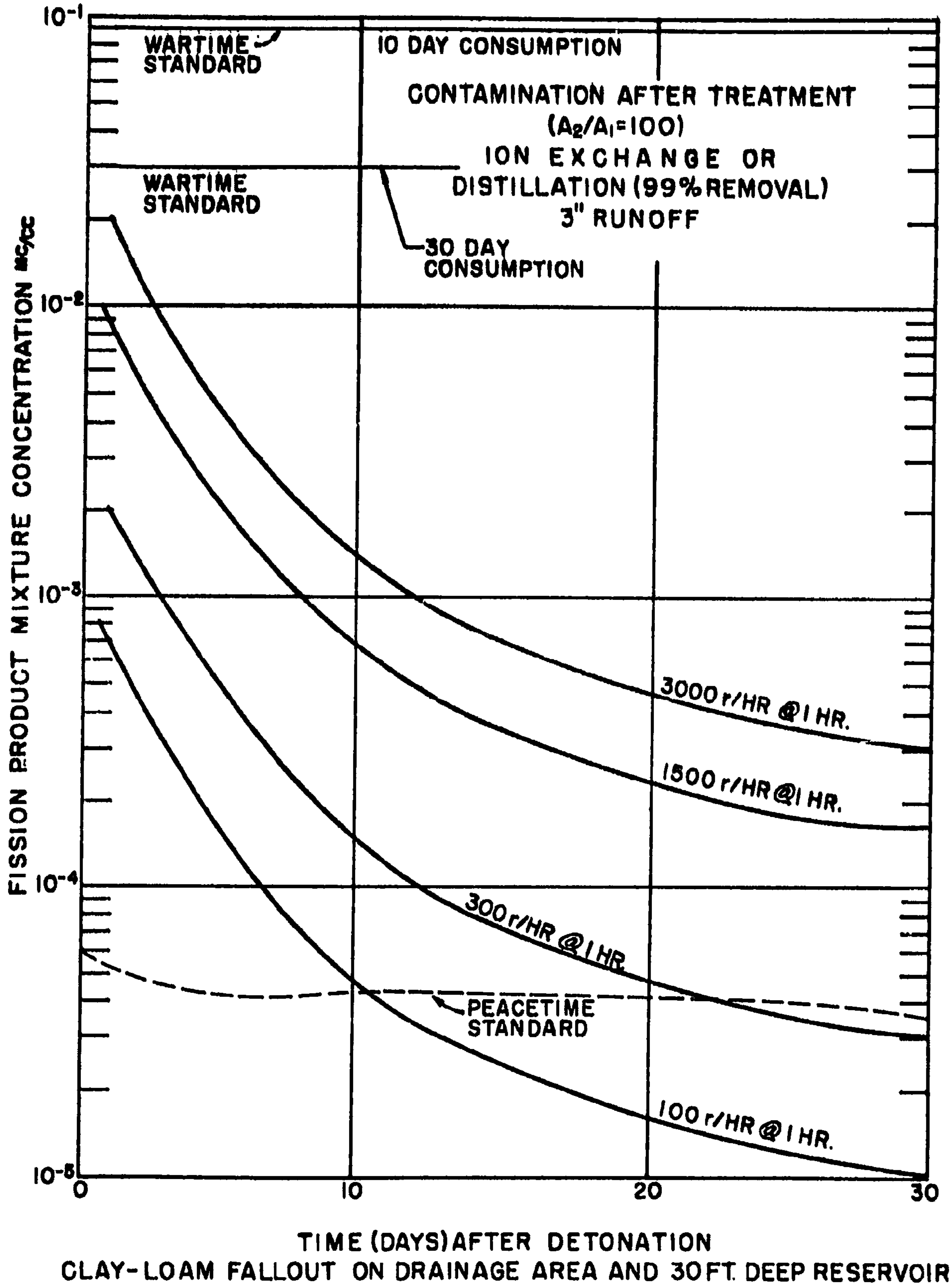


CLAY- LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR
10 % SOLUBLE
FALLOUT IN RUNOFF = 10 % OF SOLUBLE, 3% OF INSOLUBLE
FIGURE 4.33



CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR
10% SOLUBLE
FALLOUT IN RUNOFF = 10% OF SOLUBLE, 3% OF INSOLUBLE

FIGURE 4.34

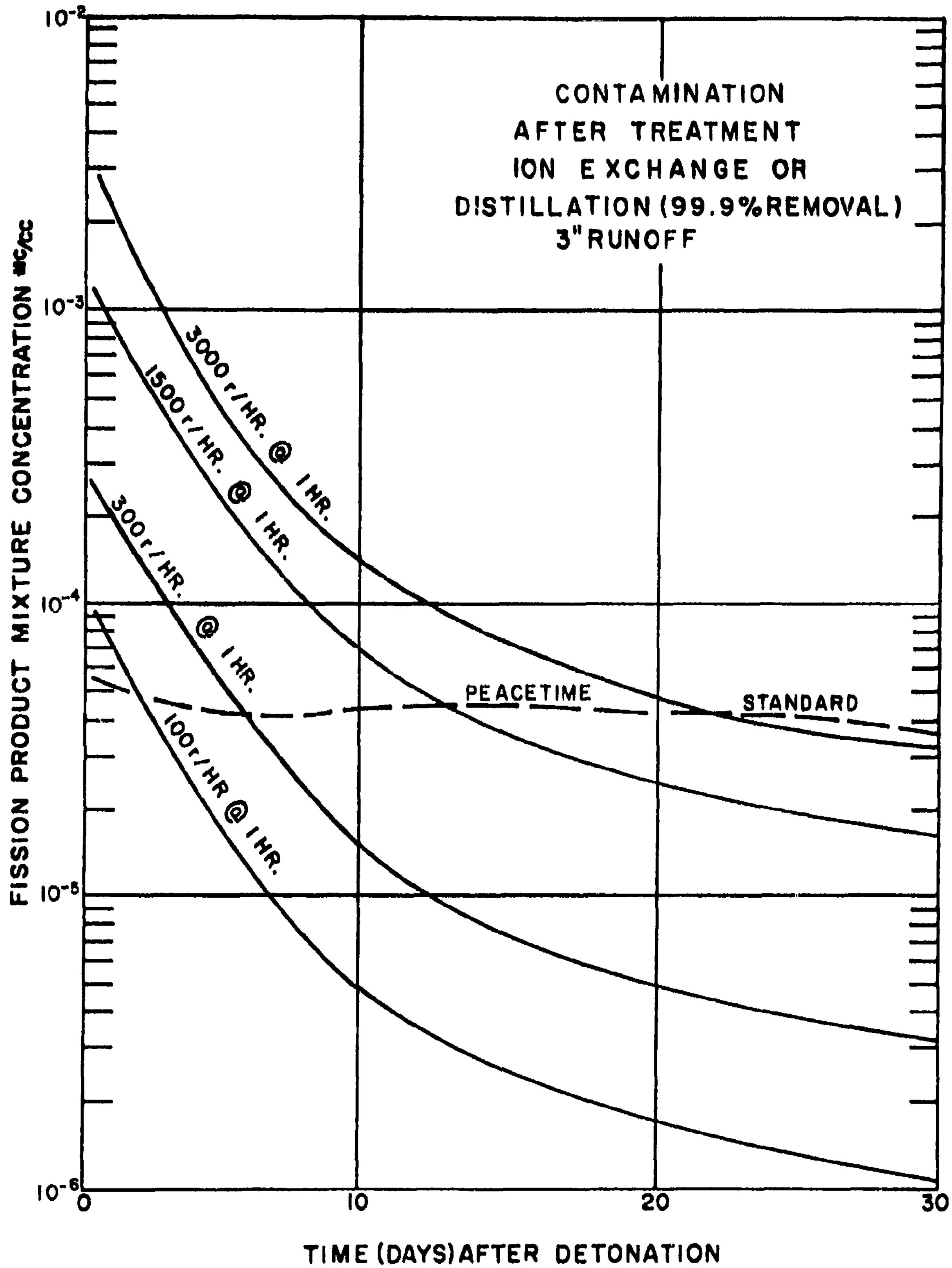


CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR

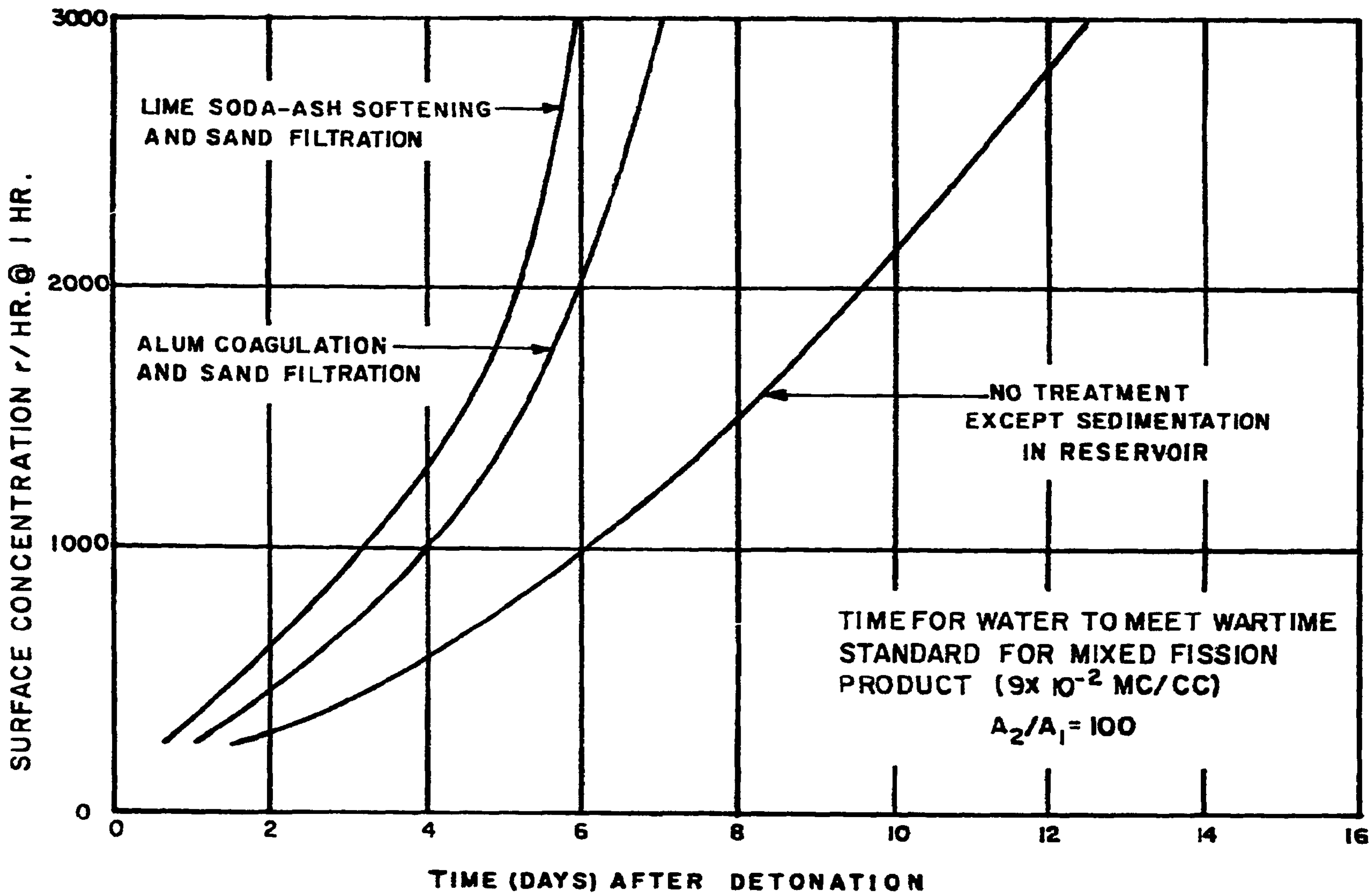
10% SOLUBLE

FALLOUT IN RUNOFF = 10% OF SOLUBLE, 3% OF INSOLUBLE

FIGURE 4.35



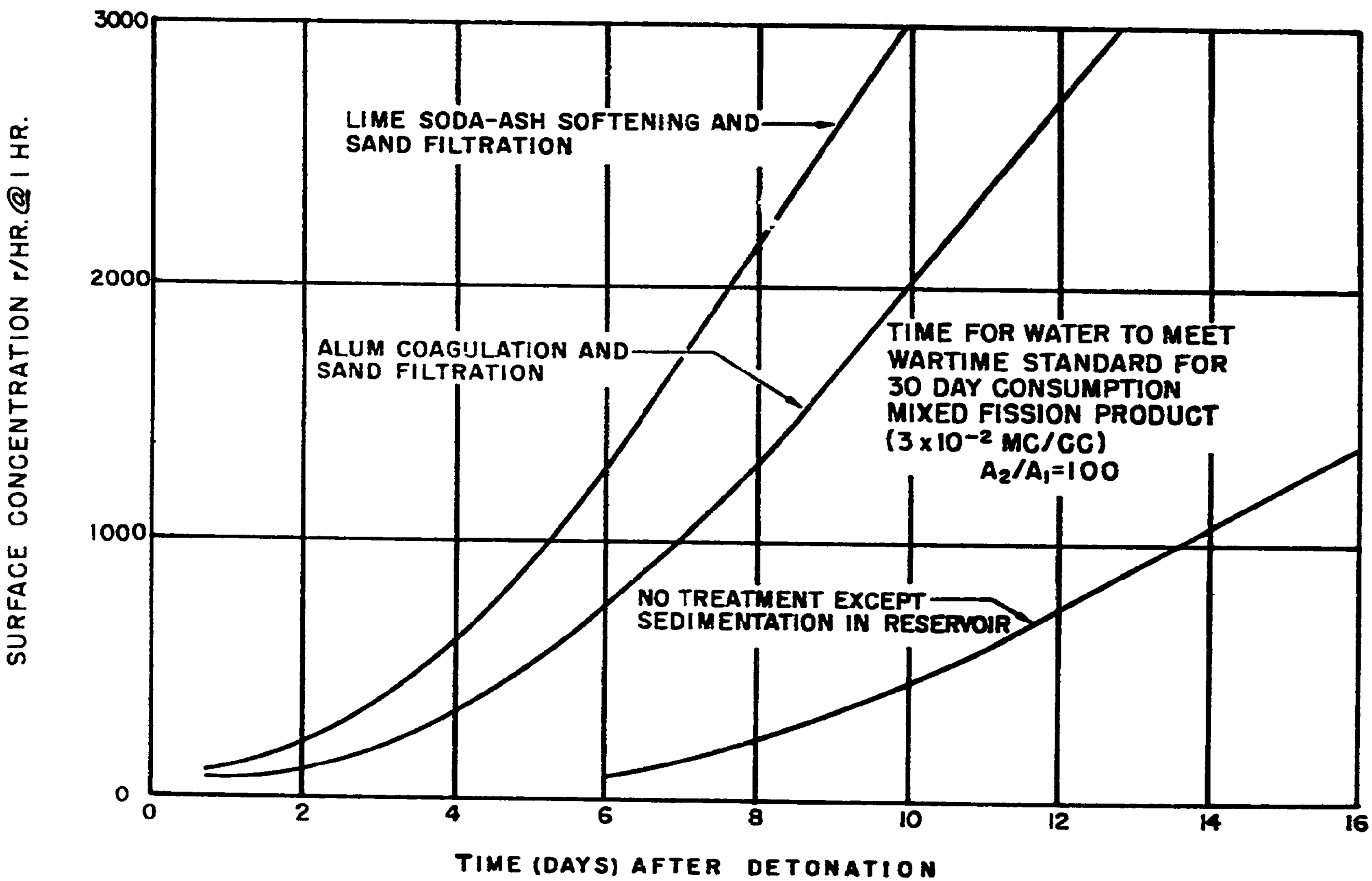
CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR
10% SOLUBLE
FALLOUT IN RUNOFF = 10% OF SOLUBLE, 3% OF INSOLUBLE
FIGURE 4.36



CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR - 10 % SOLUBLE

FALLOUT IN RUNOFF = 10 % OF SOLUBLE, 3% OF INSOLUBLE, RUNOFF = 3".

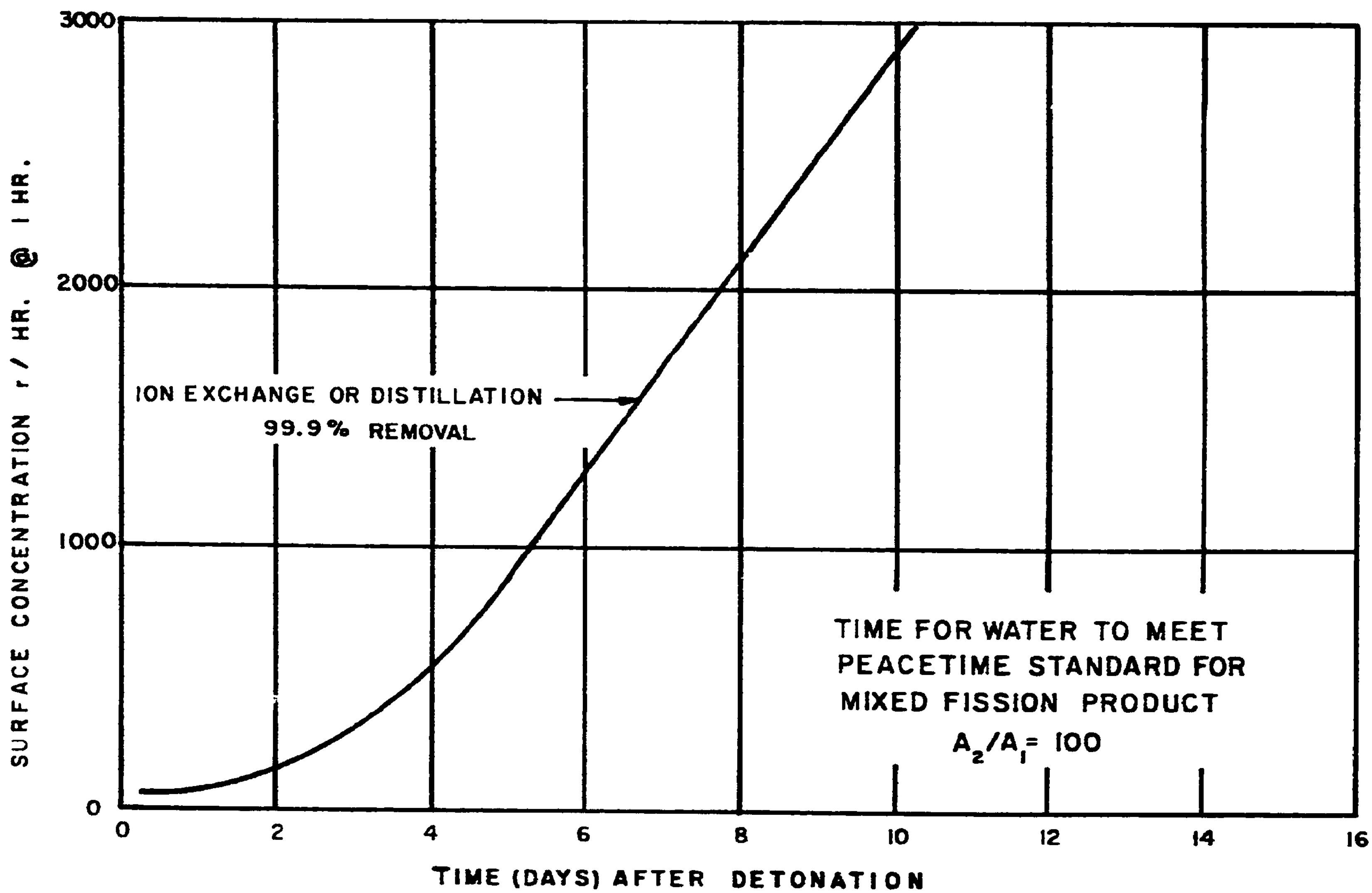
FIGURE 4.37



CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR—10% SOLUBLE

FALLOUT IN RUNOFF=10% OF SOLUBLE, 3% OF INSOLUBE, RUNOFF=3"

FIGURE 4.38



CLAY-LOAM FALLOUT ON DRAINAGE AREA AND 30 FT. DEEP RESERVOIR-10% SOLUBLE
FALLOUT IN RUNOFF = 10% OF SOLUBLE, 3% OF INSOLUBLE, RUNOFF = 3".

FIGURE 4.39

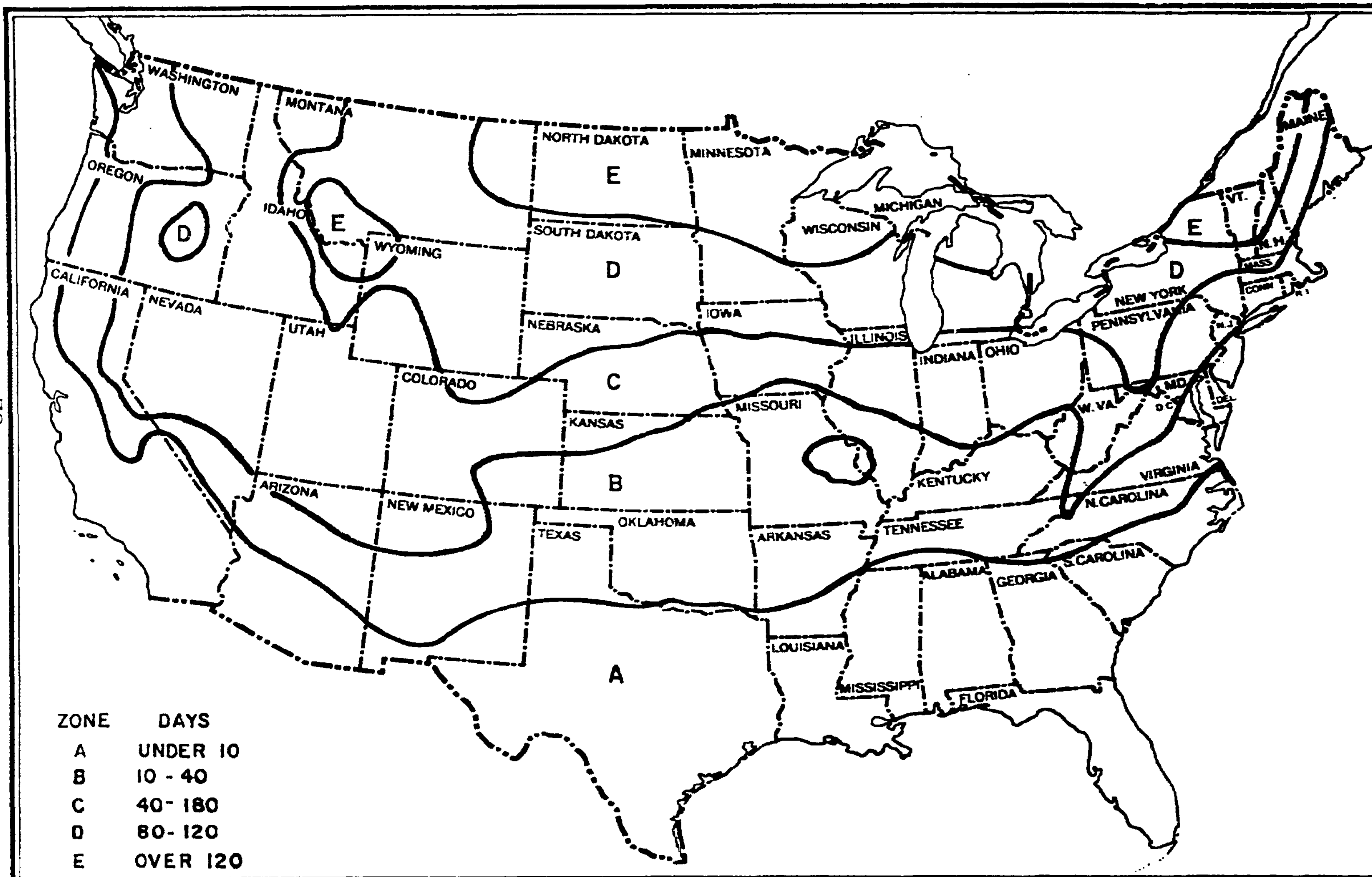
treatment processes (alum coagulation plus sand filtration and lime soda-ash softening plus sand filtration) were considered. Special treatment using ion exchange or distillation was also evaluated. Treatment efficiencies were assumed in accordance with Section 4.3.

The post-detonation time required for water, under the conditions assumed above, to meet wartime or peacetime potability standards is indicated in Figures 4.37, 4.38 and 4.39.

4.6 EFFECT OF SNOW COVER

In many sections of the United States, the ground is covered with snow for several months of the year. Similarly, open bodies of water are frozen over for significant portions of the year. These conditions would, of course, delay entry of fallout into the water system and impede the flow of contaminated runoff.

Since no control can be exercised over ice and snow, little practical value can be assessed to the subject as a solution to the survivability of water systems. However, since the "bonus" effect of these conditions could be appreciable, they are of interest. Figures 4.40 and 4.41 show extent of snow cover and frost-free periods respectively.



AVERAGE ANNUAL NUMBER OF DAYS WITH SNOW COVER (1" OR MORE)

FIGURE 4.40

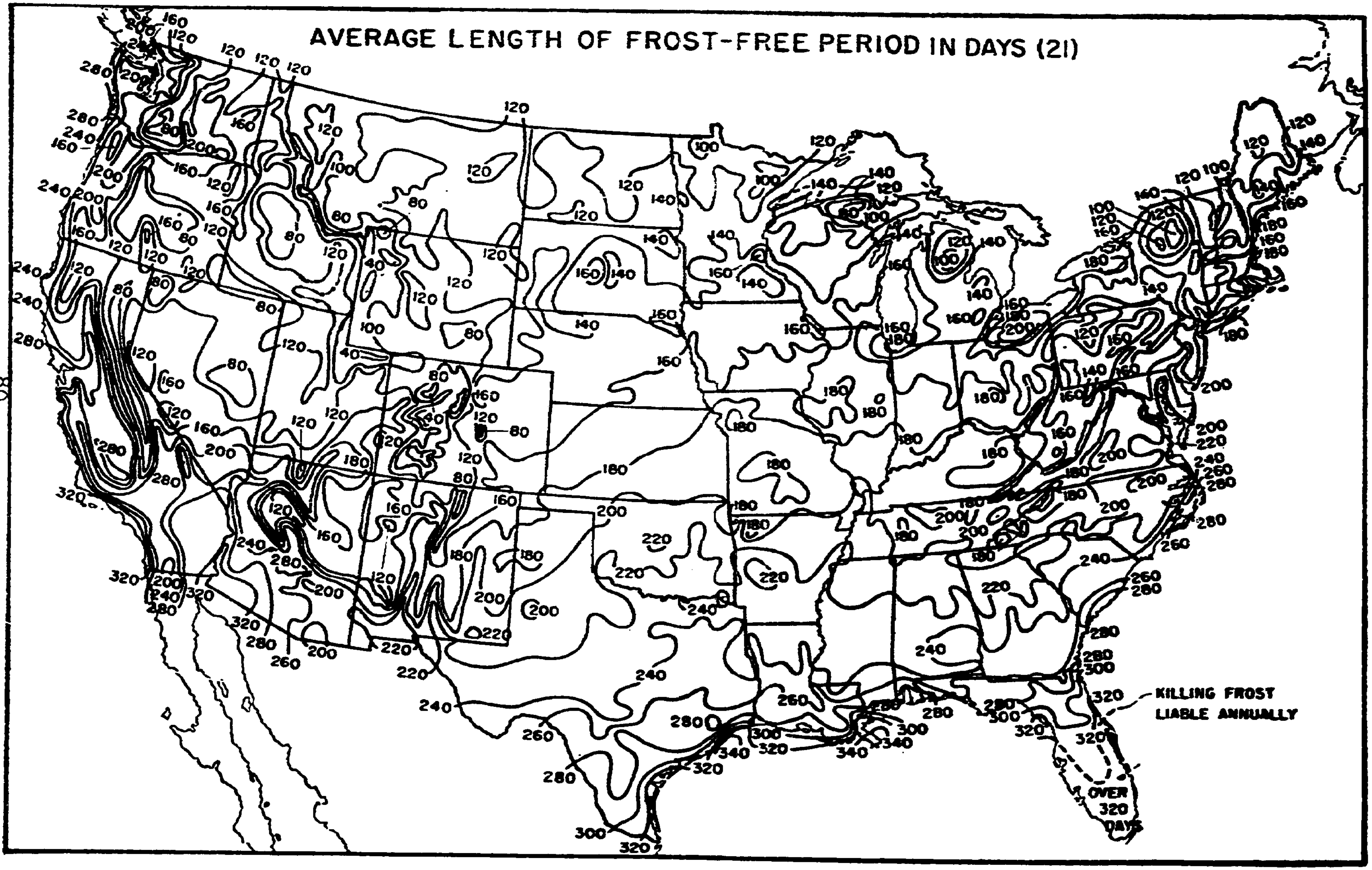

AVERAGE LENGTH OF FROST-FREE PERIOD IN DAYS (21)
KILLING FROST LIABLE ANNUALLY
OVER 320 DAYS

FIGURE 4.41

SECTION 5

REDUCING THE VULNERABILITY OF WATER SUPPLY SYSTEMS TO FALLOUT

As was demonstrated in Section 4, the degree of hazard caused by radioactive contamination of the water supply is a function of numerous parameters. For many supply systems, time delay of withdrawal is sufficient to obtain water meeting established standards of potability. For other systems under heavy fallout conditions, a high degree of contamination could result thereby requiring treatment to render the water potable.

This section will deal with protection methods in general without consideration of any specific type of system. It should be recognized that while the methods and procedures described here might be applied universally, study of each individual system is required to accurately assess its particular protection needs.

5.1 GENERAL METHODS OF REDUCING VULNERABILITY

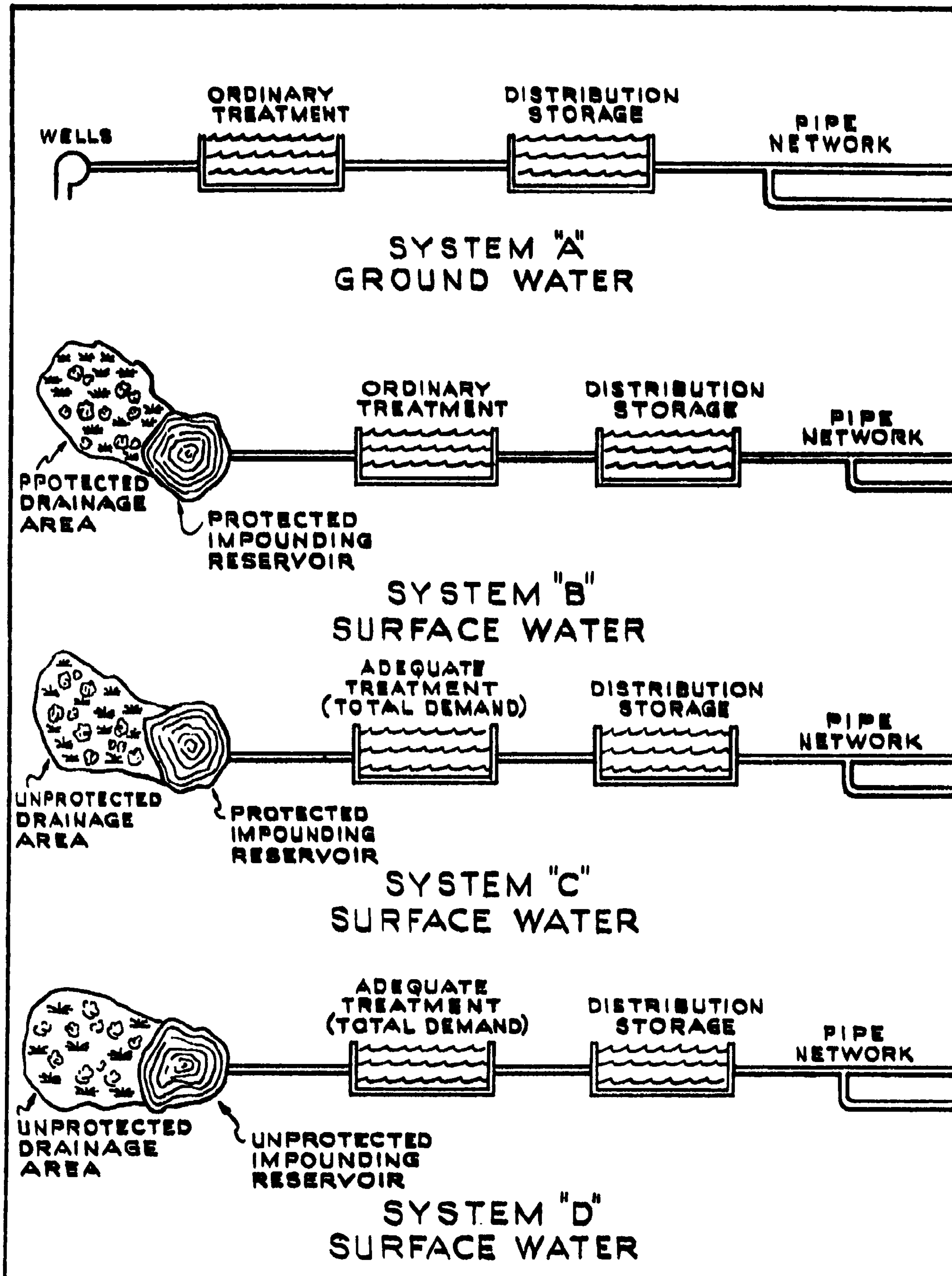
This section describes some of the broad schemes available for obtaining uncontaminated water from water systems. Specific details of the more practicable possibilities are given in Section 5.2.

Scheme "A"

Scheme "A" (Figure 5.1) represents a ground water supply which could provide a continuous supply of pure water during the shelter and post-shelter phases. This is based on the common assumption that ground water will not be seriously contaminated by fallout.

Scheme "B"

Scheme "B" (Figure 5.1) represents the theoretical ideal - a surface water supply completely protected from fallout and therefore invulnerable. However, this would entail the unrealistic requirement of protecting the entire watershed area from fallout.



REDUCING THE VULNERABILITY OF WATER SUPPLY SYSTEMS

FIG. 5.1

The scheme has little practical value, of course, especially in view of the fact that the potential hazard is not commensurate with such drastic protection extremes.

Scheme "C"

Scheme "C" (Figure 5.1) represents a case in which the impounding reservoir is protected, but the drainage area is unprotected. Surface runoff would be contaminated, and the whole system would ultimately be contaminated to some degree. Therefore, adequate treatment must be provided to insure a continuous safe supply. Just what constitutes adequate treatment depends upon the degree of contamination. As demonstrated in Section 4, ordinary sedimentation or treatment methods might suffice. Where contamination levels are high, special methods such as ion-exchange or distillation might be required to produce potable water. Treatment of the water would not have to be as extensive in this case as if the reservoir was also directly contaminated. However, under this scheme, all of the water leaving the treatment plant in this system must be potable thereby requiring large expenditures of money if special treatment is deemed necessary. The costs and requirements of protecting the impounding reservoir vs. treatment savings and efficiencies must be considered for each particular case.

Scheme "C" could provide a continuous supply of water for all purposes during the shelter and post-shelter phases.

Scheme "D"

Scheme "D" (Figure 5.1) is similar to Scheme "C" except that the impounding reservoir is unprotected and subject to direct contamination from fallout. Once again, treatment must be provided for the total demand. If special treatment techniques are required, considerable expense could be involved since all of the demand must be decontaminated.

This method could provide a continuous supply of potable water during the shelter and post-shelter phases if adequate treatment is provided, However, if water for drinking and cooking could be provided from an uncontaminated source during the days immediately following detonation (such as from stored water), the need for special treatment methods might be avoided.

Scheme "E"

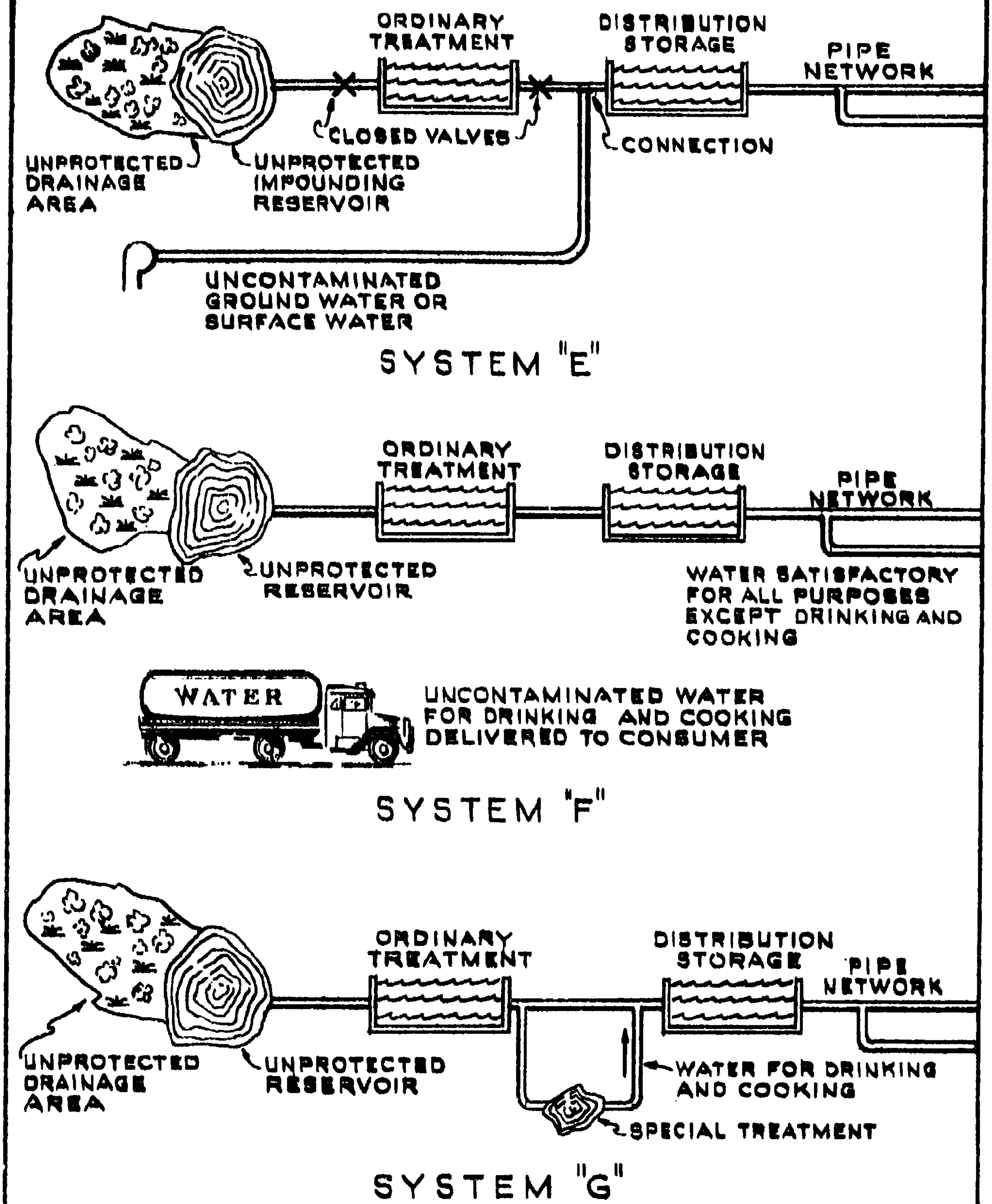
Scheme "E" (Figure 5.2) represents a case in which a contaminated surface supply can be interconnected to an uncontaminated ground water supply. The capacity of the ground water system would have to be investigated to see whether essential water demands could be supplied. Connection could be made to private or public ground water systems. In some uses, these connections already exist. In other instances, it might be possible to develop new ground water supplies for emergency connection to the surface water system.

Scheme "E" could, in many cases, provide sufficient safe water during the shelter and post-shelter phases.

Scheme "F"

Scheme "F" (Figure 5.2) represents a surface water system with unprotected drainage area and impounding reservoir. If the water is grossly contaminated, ordinary treatment may not render it potable, particularly, for the days immediately following detonation. However, the regular system could produce water for other purposes such as sanitation, decontamination, fire fighting, laundry and washing. Under this system, water for drinking and cooking would be obtained from an uncontaminated supply or by specially treating a portion of the contaminated water. Pure water would have to be hauled and distributed to the consumer.

Of course during the shelter phase, water could not be hauled and delivered, so stored water or other safe source would be required.



REDUCING THE VULNERABILITY OF WATER SUPPLY SYSTEMS

FIG. 5.2

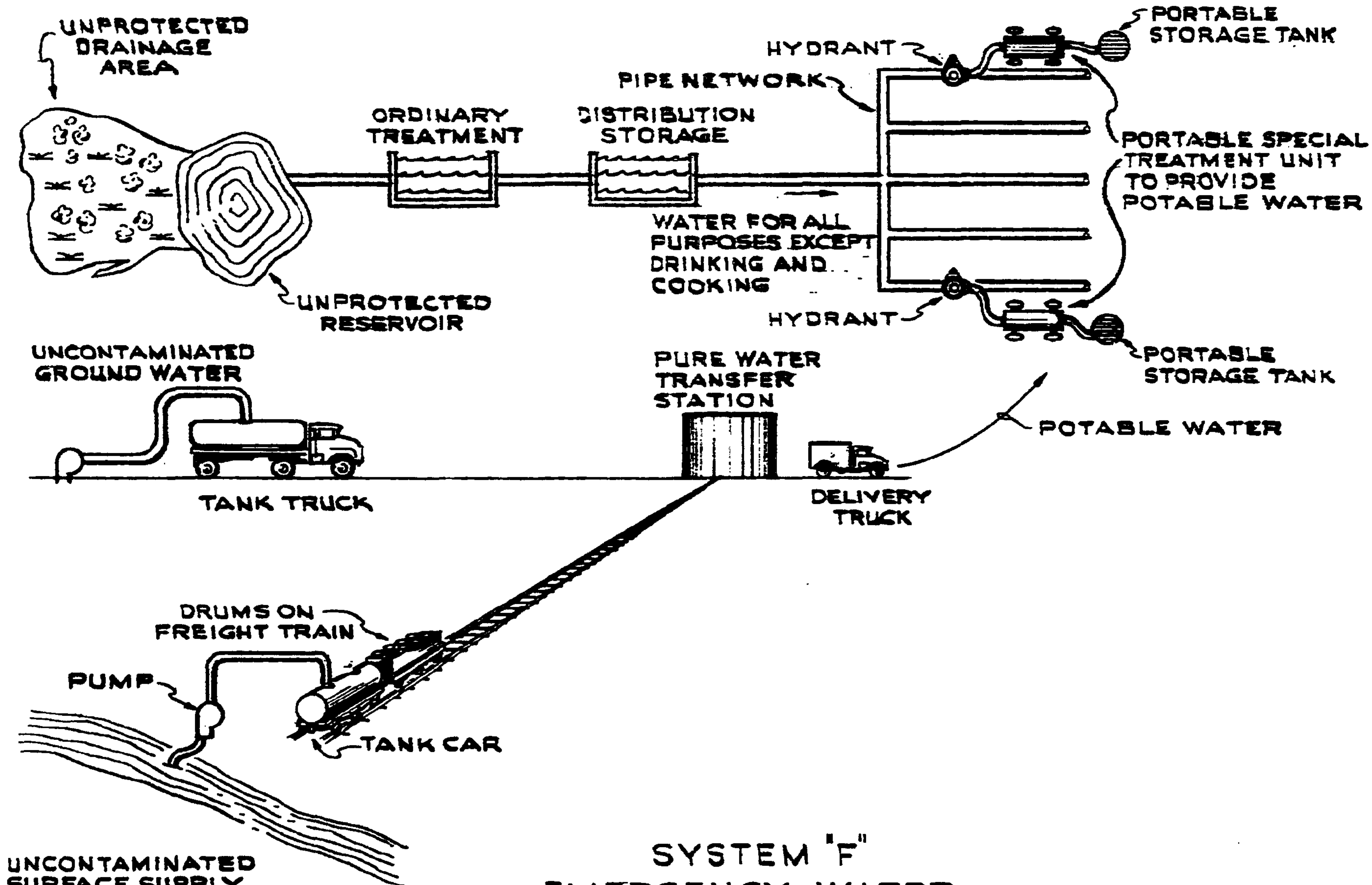
Scheme "F" would not be as convenient as some other systems, but it could provide enough potable water for all essential uses. The system could be employed as long as required to insure complete safety.

Figure 5.3 shows schematically how such a system might work. The regular system would provide water for all purposes except drinking and cooking. Uncontaminated water from a ground or surface supply would be hauled via truck or rail to a distribution center where the water would be transferred to delivery trucks for local distribution. Another solution would employ portable special-treatment plants which would take water from the pipe distribution system and render it safe for ingestion. The units would be strategically located within walking distance of a population center similar to public fountain systems still employed in some parts of the world. More detail on storage, treatment and distribution is presented in Section 5.2.

Scheme "G"

Scheme "G" (Figure 5.2) represents a surface water supply with unprotected drainage area and reservoir. Depending upon initial contamination, ordinary treatment will produce water suitable for all purposes except drinking within a relatively short time after detonation. However, a considerably longer waiting period would be required before ordinary treatment would produce a water satisfactory for ingestion. This scheme utilizes special treatment for the small percentage of water used for ingestion. Uncontaminated water from another source could be used instead of specially treated water.

Under this scheme, contaminated water is distributed as normal. At pre-designated times this water supply is shut off at the plant or pumping station and the potable water passed into the system. To distinguish between the qualities of water, a harmless vegetable dye could be added to the non-potable water to warn against its use for drinking. Of course some



SYSTEM "F"
EMERGENCY WATER
SUPPLY SYSTEM

FIG. 5.3

mixing would occur, but a color code could be established and distributed to indicate the range of potability as keyed to the color dilution.

The cost of coloring water would be approximately fifty cents per hundred gallons.

This system could function during the shelter phase as well as the post-shelter phase if operating personnel are protected and power is available.

Scheme "H"

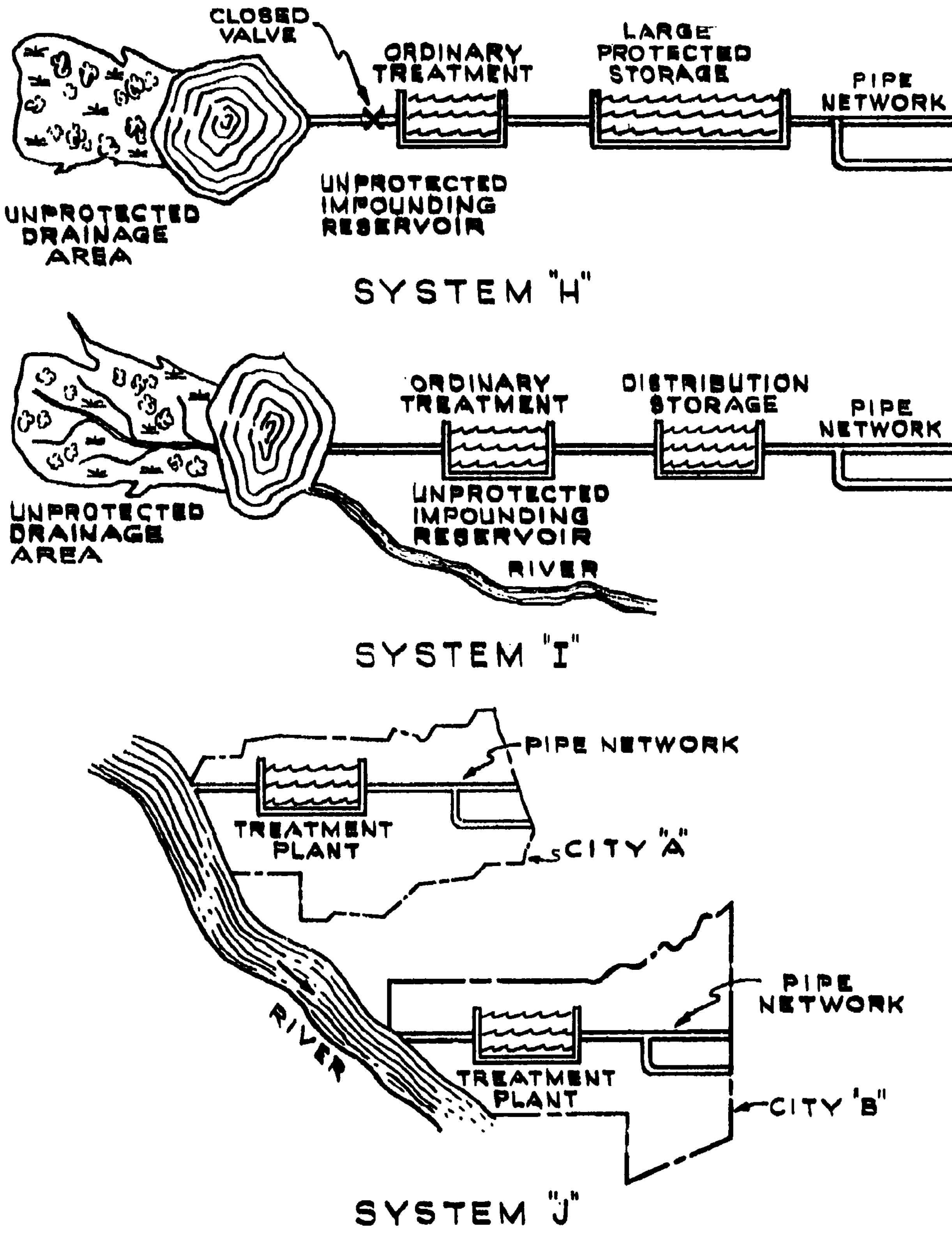
Scheme "H" (Figure 5.4) represents a surface water supply with unprotected watershed area and impounding reservoir. Some systems may contain enough protected storage in tanks, reservoirs, etc. to supply all vital needs until ordinary treatment and decay render the unprotected water suitable for consumption. A rationing system would be required in some cases.

A detailed study of storage in individual systems is required to determine if provision should be made to protect or isolate unprotected storage in the distribution system.

Scheme "I"

Scheme "I" (Figure 5.4) represents a large surface water supply. A well planned monitoring system and flexible operating system could go far toward reducing vulnerability. Contaminated water could be wasted to the river. In some cases contaminated water could be bypassed around the reservoir. It may be possible to draw water from an uncontaminated or slightly contaminated part of the system. Reservoirs could be flushed out to reduce contamination.

Very large systems would present many opportunities to provide a good quality water through proper operation. However, each system would require individual study and careful planning before and after a nuclear attack.



REDUCING THE VULNERABILITY OF WATER SUPPLY SYSTEMS

FIG. 5.4

Scheme "J"

Scheme "J" (Figure 5.4) represents the case where several cities draw water directly from a large river. Fallout could occur directly on the river and on the drainage area. Fallout occuring directly on the river would soon contaminate the water and be carried downstream depending on the flow characteristics. The major slug of contamination would be carried past a city in a relatively short time. However, the water supply of cities downstream of significant fallout could be contaminated. Detailed studies have been made of this problem. (22)

A possible solution for a large river consists of a forecasting system similar to present flood forecasting methods. This would require a monitoring network, planning and computer center and a communication system. Cities along the river could be kept informed of the present and anticipated contamination and the water supply systems operated to provide the best quality of water available. A contamination forecasting system would not make a system invulnerable but would reduce the vulnerability considerably.

Contamination may also be introduced into this system if large amounts of water are used for decontamination at City "A". Such water would be carried primarily by the storm sewer system into the river and possibly contaminate the supply of City "B" downstream. The seriousness of the problem depends upon how much fallout is washed into the river and how much dilution will occur in the river.

The problem could be minimized by curtailing the water supply of City "A" although this would be a drastic measure. Rules controlling decontamination procedures and public education would be useful. A plan could be developed in which City "A" decontaminates during a specific period and City "B" is advised not to withdraw water when the contaminated water passed the intakes. Heavy rains are more of a problem since they would probably wash more fallout into the river than decontamination procedures. An efficient monitoring system along the river would permit the best utilization of water. Of course, if fallout is heavy and widespread, alternate supplies and protective measures discussed for other schemes might be required.

An integrated study of the whole river basin would be a necessary requisite toward developing this scheme as well as a closely coordinated operating plan to be followed by the affected cities.

5.2 SPECIFIC METHODS OF REDUCING VULNERABILITY

This section describes some of the methods and details by which the protection schemes listed in section 5.1 could be effected.

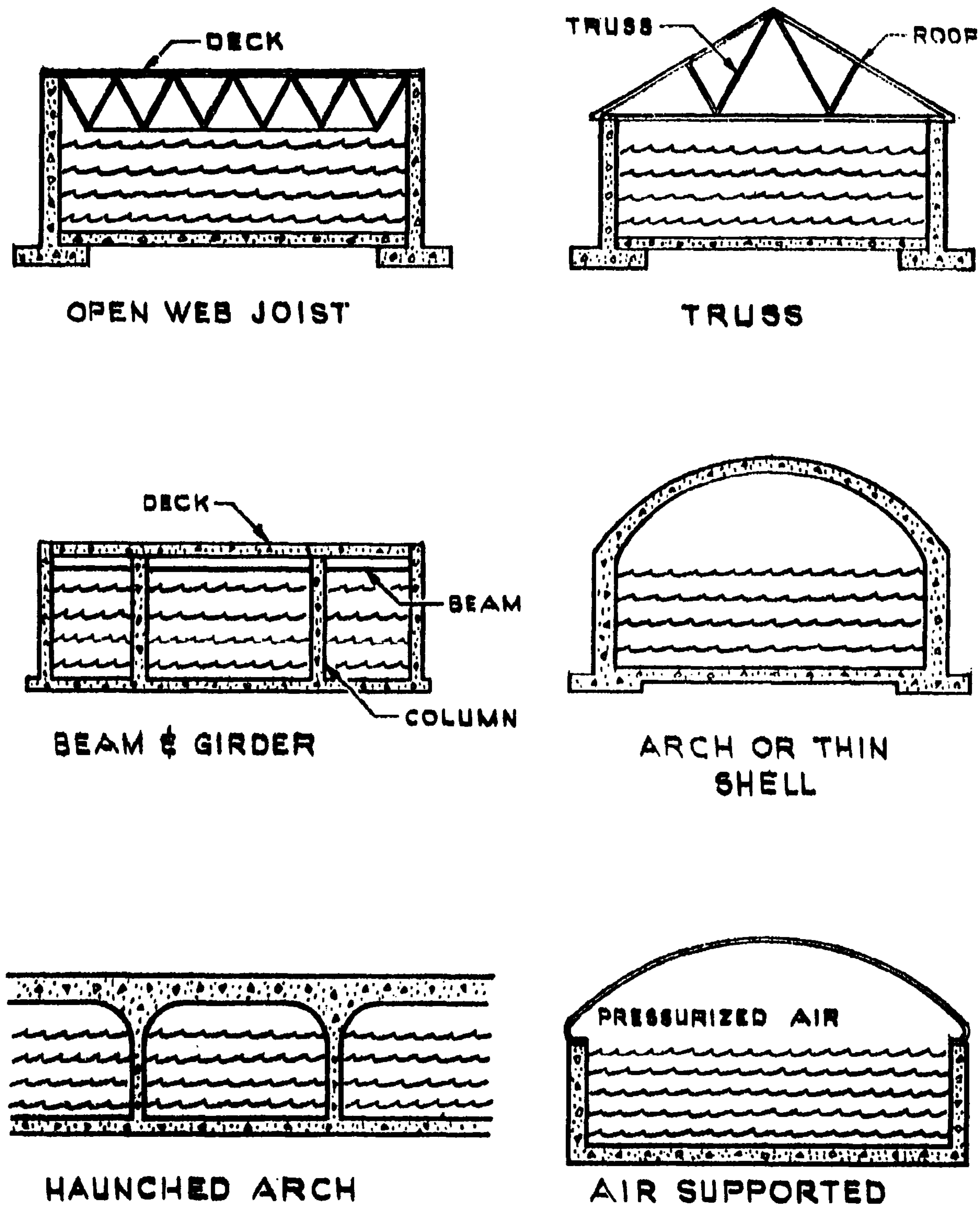
5.2.1 Protecting Water in Exposed Tanks and Reservoirs

Impounding reservoirs, distribution reservoirs and open tanks in the treatment plant or distribution system are vulnerable to fallout if not protected.

One apparent method of protection is to prevent fallout from falling into exposed water surfaces. This might be accomplished by using mechanical blowers to prevent the fallout particles from descending. Fires around or on the reservoir could be used to create an up-draft and reduce the descent of radioactive particles. These methods are presently used to dispel fog but require additional study to determine their efficiency in this application.

A more conventional method of protecting reservoirs, of course, is to provide protective covers. Several types of rigid and non-rigid covers are available.

5.2.1.1 Rigid Covers - A few of the many possible types of rigid covers are indicated in Figure 5.5. All of these structures would have to be designed to support snow, wind, ice and dead loads according to geographic location. Open web steel joists are available for a wide assortment of span and load conditions. Specifically designed trusses can be used in a similar fashion for



PROTECTING RESERVOIRS
—RIGID COVERS

FIG. 5.5

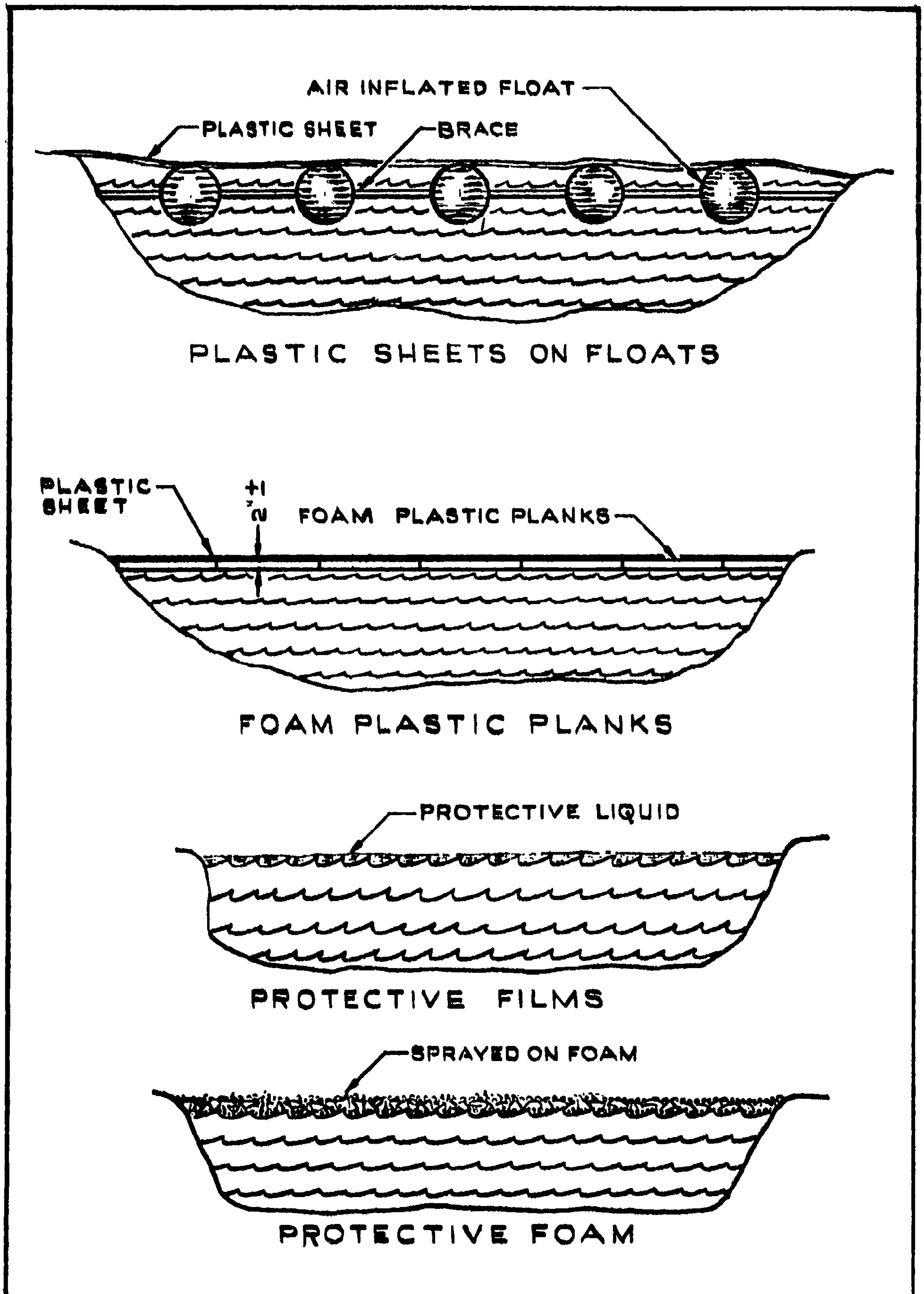
longer spans. Concrete tanks can be covered using a beam and girder construction with intermediate column supports. A variation of this construction commonly used for pure water storage is a haunched arch or flat slab. Arch, dome or thin shell construction similar to many gymnasium roofs could be used for wide spans. Light weight roofs supported by air pressure have been used for reservoirs and buildings. Cable supported roofs present another possible solution. The selection of a particular type of cover depends primarily upon span, loads and, ultimately, upon costs.

5.2.1.2 Non-Rigid Covers - More economical covers of a temporary nature could be constructed of polyvinyl sheets supported on rubber or wooden rafts. (Figure 5.6).

Provision for the evaporation or drainage of rain water would be required. Covers for tanks and distribution reservoirs of moderate size could be stored at the site and placed in position in a relatively short period of time. Large impounding reservoirs would require long warning periods and covers might have to be installed on a permanent basis.

Another possibility consists of a floating cover of polystyrene foam approximately 2 inches thick. This material comes in planks or in rolls, and could be floated into position and covered with a thin sheet of polyvinyl or other suitable material. (Figure 5.6) Provision for supporting or draining snow and rain would have to be made. Moderate sized tanks and reservoirs could be quickly and easily covered in this fashion at a reasonable cost.

A protective layer of liquid that could be easily distributed over a large reservoir and prevent fallout particles from entering the water is another possible solution. The liquid would be in the nature of a viscous oil that would float on the water but not mix with it. It would be applied in a layer of sufficient thickness to envelop the fallout particles and prevent them from descending into the water. An arrangement could be developed to apply the liquid automatically



PROTECTING RESERVOIRS

FIG. 5.6

when a nuclear attack seems imminent. A foam similar to that used for fire extinguishing might serve a similar purpose. However, experimental research may be required to find a protective liquid suitable for this purpose.

5.2.2 Protecting Operating Personnel

The need for protecting operating personnel has been emphasized in Section 3 of this report and must be considered in the detailed study of individual water supply systems. If a study indicates that a system should be shut down because water of satisfactory quality could not be supplied during the shelter phase, conventional fallout shelters for operating personnel may suffice. However, even contaminated water would be useful during the shelter phase for sanitary purposes, fire fighting, decontamination, etc. Therefore, it may be desirable to plan for operation of the water system during the shelter phase even if the water is not potable.

If continuous operation of the water system is planned, provisions will be required to protect personnel. Entire treatment plants or pumping stations will have to be made safe against fallout intrusion. Remote operation of equipment and valves from protected areas should be considered where necessary, as well as automatic operation of equipment where applicable. Conversion of existing systems to remote or automatic operation may be very costly in some cases. However, because of the inherent advantages of this mode of operation, long range plans for new or modernized water supply systems should take them into consideration.

The possibility of accumulations of radioactive material in various parts of a system must also be considered. Sedimentation tanks, ion exchange units and sand filters may present a hazard to operating personnel when treating a grossly contaminated water. Safety precautions and methods now used to dispose of peacetime radioactive wastes will be required.

5.2.3 Training Personnel

One of the most important ways of reducing the vulnerability of a water system is to insure the availability of well trained personnel who can operate efficiently in an emergency. The need for training water supply personnel in the use of radiological detection equipment has long been recognized and implemented. This program should be continued.

It is equally important that sufficient numbers of well-trained personnel be available for the ordinary operation of a system. Casualties, fallout or general chaos after an attack may require that individuals perform duties outside their usual responsibilities. A manpower pool of laborers, pipe fitters, electricians, etc., that could be diverted to repair and operate water supply systems is advisable. There is also a need for men familiar with the overall operation of each system. The complexity of modern water supply systems makes it imperitive that efficient supervisory personnel be available.

5.2.4 Insuring the Availability of Power

The availability of power must be considered in any vulnerability study of a water supply system. Water systems are highly dependent upon electrical power for the operation of pumps, chemical feeders, mixers, flocculators, sludge collectors, disinfection equipment, controls, etc. Nearly every system would be affected to some extent by a power failure. Some systems would be completely inoperable.

Of course, the possibility of a power failure due to equipment breakdown, storms, fires, earthquakes or other peacetime disaster is always present, and all water systems include provisions for operating under emergancy conditions. Some provisions commonly made for emergency peacetime operation that apply equally well in time of nuclear war are:

a. Tie in to a power grid.

b. Emergency stand-by electrical generators.

c. Dual-operated equipment (particularly pumps).

d. Stored water (preferably elevated storage).

e. Provision to by-pass non-essential equipment.

f. Portable or mobile engines, generators or pumps.

g. Manual operation of equipment.

Each system requires individual study to determine what provisions should be made to permit operation in the event of a power failure during a nuclear war. In many cases, no provisions beyond those already available will be necessary. Provision should be made to supply at least a minimum quantity of water during any emergency in which there are likely to be survivors. It may be necessary to abandon all usual treatment except disinfection, but automatic or manual applications of chlorine or hypochlorite solution are particularly important.

5.2.5 <u>Alternate Water Sources</u>

Alternate sources of satisfactory water may be available to replace or supplement a damaged or contaminated water system during the shelter or post-shelter phase.

5.2.5.1 <u>Uncontaminated Surface Water</u> - It is possible that surface waters not usually used as a water supply system may be uncontaminated and used during an emergency. Streams, lakes or rivers may be adapted for emergency use if the required piping and pumping equipment is available. Disinfection would be normally required as a minimum treatment. Radiological monitoring equipment would be required to determine the quality of various supplies.

Because of the uncertainty of the extent of fallout, extensive pre-attack development of alternate surface water supplies does not seem warranted. However, the acquisition of portable pumps, hose and disinfecting and monitoring equipment should be carefully considered as part of the over-all plan for a particular system.

5.2.5.2 Ground Water

Ground water from deep aquifers is considered to be a reliable source of water which will not be contaminated by fallout. As previously pointed out, precipitation may be contaminated in the air or on the surface of the earth. However, much of the contamination will be removed during the slow descent of the water through the soil. Radioactive decay will be effective during the extended time required for precipitation to reach the deep aquifers. It cannot be taken for granted, however, that shallow or highly porous aquifers will not be contaminated. Also, the possibility of ground water contamination over long periods of time by heavy concentrations of long-lived isotopes should be investigated. The possibility of utilizing ground water in a particular area will require detailed study.

The potential availability of ground water is demonstrated by Figures C.16 and C.17 which indicate the location of the major ground water areas in the United States. Figure 5.7 indicates the quantity of fresh ground water used in the U.S. as of 1960 (23). Quantities are expressed in million gallons per day by states. Also indicated on Figure 5.7 is the quantity of fresh ground water available per person as of 1960. Quantities are expressed in terms of gallons per capita per day and were obtained by dividing the volume of water available per day by the population. These figures indicate that ground water could meet vital demands during emergency periods, at least on a statistical basis. Of course, more detailed study is required to determine the actual relationship between ground water availability and population distribution.

Table 5.1 and Figures 5.8 and 5.9 summarize the results of a study of the 70 most populated metropolitan areas in the United States. (3) The table

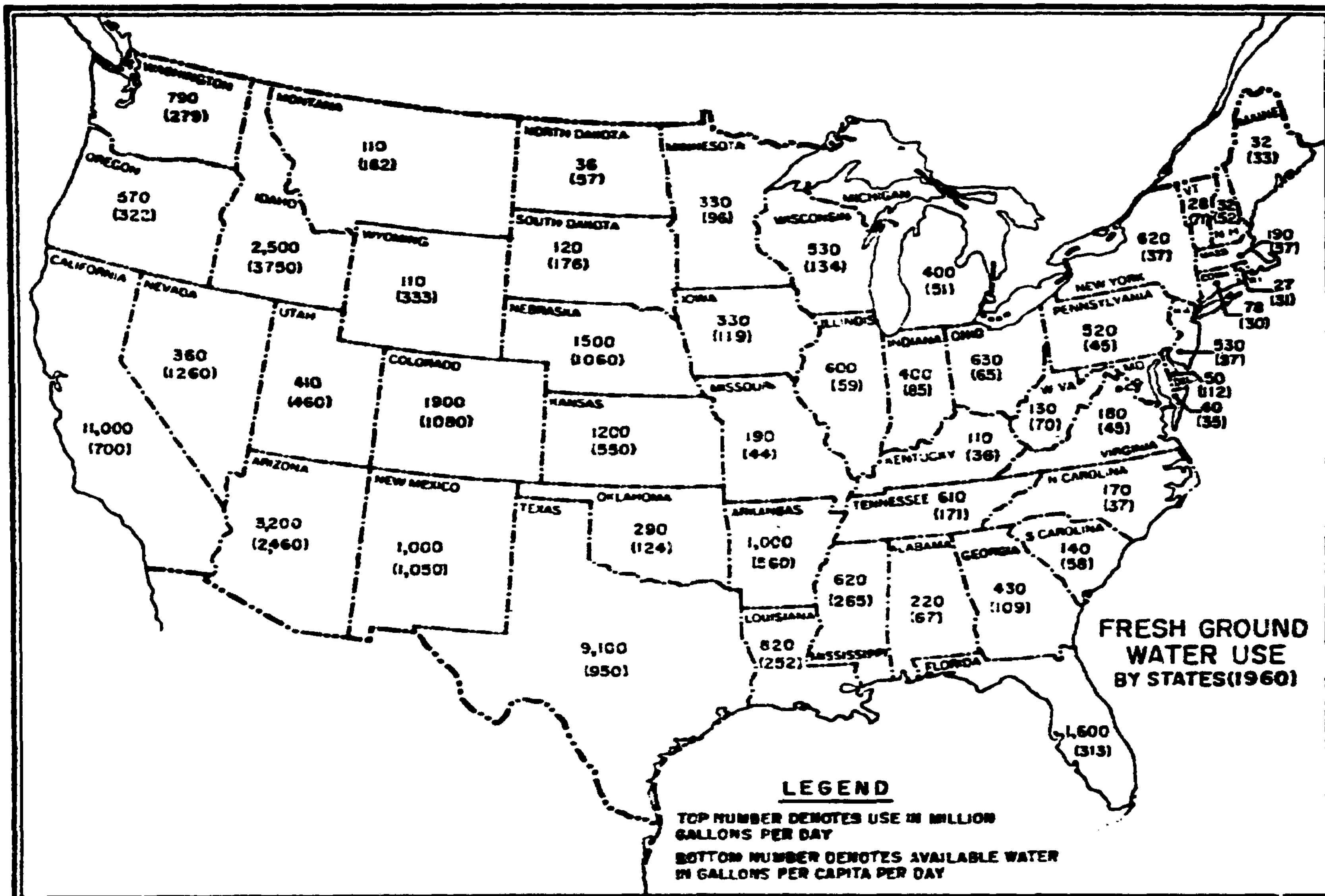

FRESH GROUND WATER USE
BY STATES(1960)
LEGEND
TOP NUMBER DENOTES USE IN MILLION GALLONS PER DAY
BOTTOM NUMBER DENOTES AVAILABLE WATER IN GALLONS PER CAPITA PER DAY
WASHINGTON 790 (279)
OREGON 570 (322)
CALIFORNIA 11,000 (700)
NEVADA 360 (1260)
IDAHO 2,500 (3750)
MONTANA 110 (182)
WYOMING 110 (333)
UTAH 410 (460)
ARIZONA 3,200 (2,460)
COLORADO 1900 (1080)
NEW MEXICO 1,000 (1,050)
NORTH DAKOTA 36 (57)
SOUTH DAKOTA 120 (176)
NEBRASKA 1500 (1060)
KANSAS 1200 (550)
OKLAHOMA 290 (124)
TEXAS 9,100 (950)
MINNESOTA 330 (96)
IOWA 330 (119)
MISSOURI 190 (44)
ARKANSAS 1,000 (560)
LOUISIANA 820 (252)
WISCONSIN 530 (134)
ILLINOIS 600 (59)
MICHIGAN 400 (51)
INDIANA 400 (85)
OHIO 630 (65)
KENTUCKY 110 (36)
TENNESSEE 610 (171)
MISSISSIPPI 620 (265)
ALABAMA 220 (67)
GEORGIA 430 (109)
FLORIDA 1,600 (313)
S CAROLINA 140 (58)
N CAROLINA 170 (37)
VIRGINIA 180 (45)
W VA 130 (70)
PENNSYLVANIA 520 (45)
NEW YORK 620 (37)
VT 28 (32)
N H 32 (52)
MAINE 32 (33)
190 (37)
27 (31)
78 (30)
530 (37)
50 (112)
40 (35)

FIGURE 57

TABLE 5.1

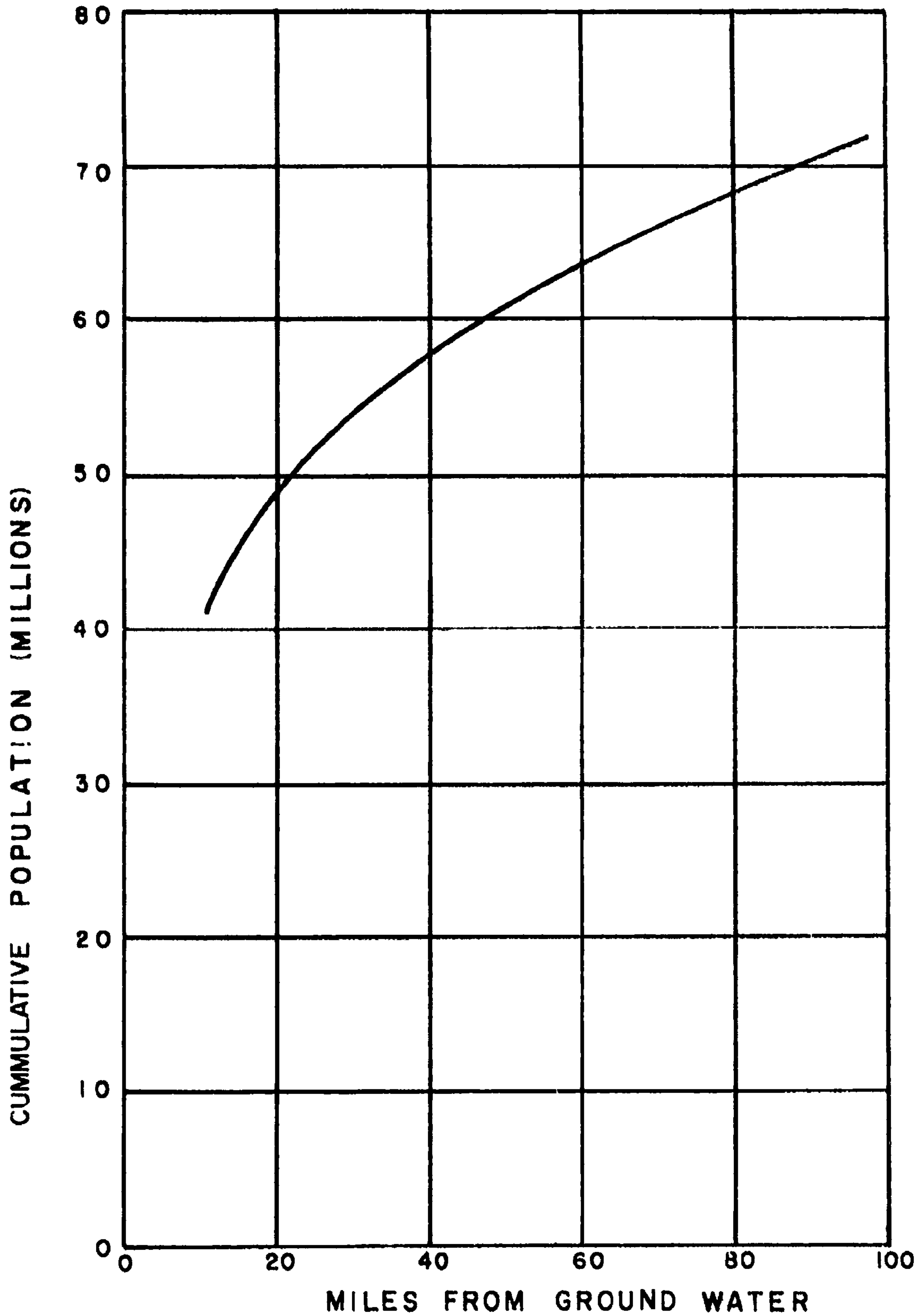
Availability of Ground Water for the 70 Most - Populated Metropolitan Areas in the Country.

Proximity to Developed Ground Water (1)	Population (2)(3)	Cumulative Population
0 - 10 mi.	43,861,000	43,861,000
10 - 20	817,000	44,678,000
20 - 30	10,153,000	54,831,000
30 - 40	2,545,000	57,376,000
40 - 50	4,546,000	61,922,000
50 - 60	1,378,000	63,300,000
60 - 70	3,429,000	66,729,000
70 - 80	2,143,000	68,872,000
80 - 90	665,000	69,537,000
90 - 100	---	
100 +	2,886,000	72,423,000
	72,423,000	

(1) Ground water data from the U.S. Department of Health, Education and Welfare. (24)

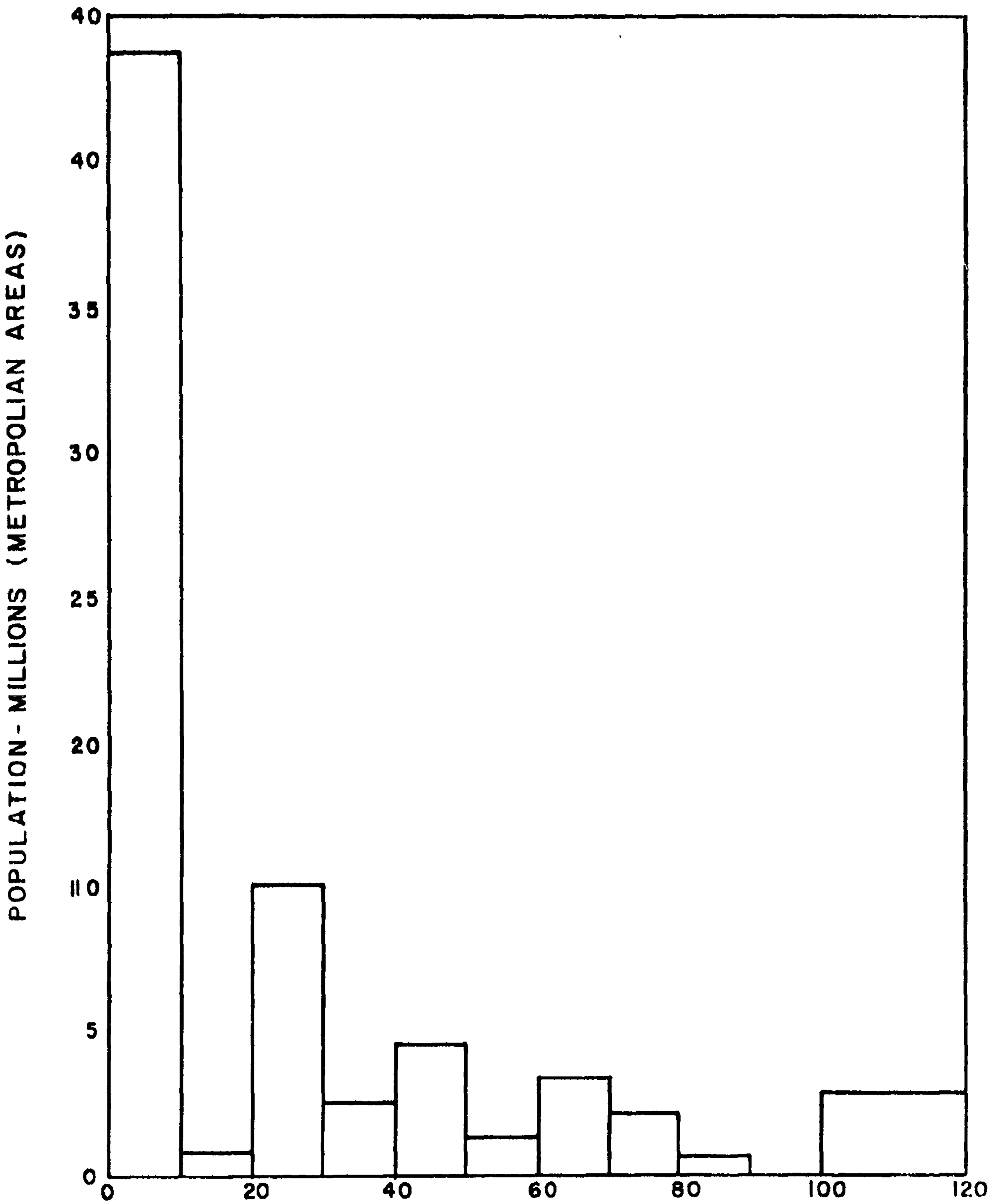
(2) Population Figures do not include the communities which are the potential suppliers of the ground water if they are not in the group of 70 most populated metropolitan areas.

(3) This figure includes the population of metropolitan areas in the first 70 group which currently use ground water.



AVAILABILITY OF GROUND WATER

FIGURE 5.8



MILES FROM AVAILABLE GROUND WATER

AVAILABILITY OF GROUND WATER

FIGURE 5.9

and graphs indicate the number of people living in the 70 areas, who could be provided with ground water from existing systems. They also indicate the proximity of segments of the population to developed sources. The actual quantity of water available would be required for a more complete evaluation of the problem. (This phase is being investigated in a concurrent report by Guy B. Panero Inc.) (28) The study indicates that approximately 70 million people in the areas considered are within 90 miles of a developed ground water supply. Additional millions of people in small cities and rural areas (Figure C.10) could be also supplied with ground water.

5.2.6 Radiological Monitoring

One of the most important methods of reducing the vulnerability of a water supply system is an efficient radiological monitoring and communication system. It is essential that operating personnel be continuously informed as to the degree of contamination in various parts of the system to permit optimum operation of existing facilities. It is equally important to inform the public of the suitability of water for various uses.

Instruments capable of providing a continuous record of contamination of raw and treated water should be provided. In addition, the desirability of installing monitoring instruments at strategic points in the collection system should be investigated. Provision for telemetering basic information to a control center at the treatment plant should be considered. The type of monitoring equipment required depends primarily upon whether or not the plant is to be operated continuously during the shelter phase.

Informing the public of the potability of the water can be accomplished by ordinary mass communication media such as radio or television if they are operating. If these or other communication systems are not available, monitoring instruments suitable for determining water contamination should be developed and made available for use by the general public. These should preferably be widely distributed, simple, economical devices for determining the potability of water. Some indicator not requiring power, of the type now used for measuring external radiation, would be preferable.

Identification of pure or contaminated water by coloring with harmless vegetable dye has been previously mentioned. (Section 5.1) This method could be used to inform the public of water condition if other communication media are not available. Coloring could also be used to identify water where the same distribution system is used for pure and contaminated water. A color code utilizing various colors and shades could be used to represent varying degrees of contamination.

Several colors are available at reasonable cost. The dye could be introduced into the system at the treatment plant or any other convenient point in the system. Of course, further study and experimentation are needed to ascertain the feasibility and ramifications of this approach.

5.2.7 Treatment of Contaminated Water

If radioactive contamination cannot be avoided, treatment may be required to produce water of satisfactory quality. Several types of systems are available - each with degrees of efficiency dependent upon various factors and applications. Much study has been devoted to this subject and detailed practices published. Some of the more usual methods and their efficiencies are summarized in the Table 5.2.

The efficiency of various treatment processes for reducing radioactivity has been investigated in the laboratory and to a small extent in field tests. (24) The efficiency varies with many factors including type of treatment, contaminants present and solubility of the fallout.

TABLE 5.2

EFFECTIVENESS OF TREATMENT PROCESSES FOR REMOVING A MIXED FISSION PRODUCT (24)

Treatment	Percent Removal
Coagulation plus filtration	60-80
Clay slurry pretreatment plus coagulation plus filtration	80-90
Lime-soda ash softening plus filtration	60-90
Ion exchange slurry plus coagulation plus filtration	85-98
Coagulation plus filtration plus post-ion exchange	99-99.9
Distillation	99-99.999

5.2.7.1 Minor Modifications to Existing Treatment Plants - In some cases, monor modifications to an existing treatment plant or to its method of operation can be used to increase the removal of radioactivity. For example, a slurry of local clay added prior to coagulation has been found to increase efficiency of decontamination. The clay may have some natural ion exchange properties and also serves to increase the turbidity, thus encouraging the formation of a floc and the removal of fallout by sedimentation.

A disadvantage of this method is the necessity of handling large volumes of radioactive sludge. However, it has the advantage of requiring little advance planning or stockpiling, and might be used to advantage in an emergency.

The efficiency of coagulation has been found to vary according to the type and amount of chemicals used. Laboratory tests using ferrous sulfate, ferric chloride, aluminum sulfate, activated sodium silicate, calcium hydroxide, sodium carbonate, limestone and sodium hydroxide are reported in reference (2). Tests indicate that the addition of certain chemicals to contaminated water is effective in removing particular isotopes. It has been found, for example, that small amounts of copper sulfate, activated carbon or silver nitrate increase the removal of I^{131}. This suggests the possibility of adding selected chemicals to public water supplies for the purpose of removing particularly objectionable isotopes. This method requires a knowledge of the isotopes present and the amount and type of chemicals to use. The overall removal of radioactivity may be relatively low. However, this method has the advantage of being easily adaptable to use in existing coagulation - filtration plants. Chemicals would have to be stockpiled or easily obtainable, and in some cases new chemical feed equipment would be required.

The addition of excess chemicals in the lime-soda ash softening process has been found to increase removal of strontium, barium, cadmium, yttrium, scandium, and zirconium - niobium. The application of 200 ppm excess lime-soda ash reduced the strontium content by 99.4 percent. This method could be used in existing lime-soda ash softening plants and in coagulation-filtration plants. Chemicals could also be added in impounding or distribution reservoirs in an emergency.

Mixed ion exchange resins have been found very effective (over 99 percent) in removing radioactivity from water. They can be added as a slurry prior to coagulation. However, the most effective resins are costly (approximately $60 per cubic foot) and become ineffective unless frequently regenerated. The use of resins as a pretreatment without regeneration would be very costly.

It may be possible to adapt a section of an existing rapid sand filter to be used as an ion exchange unit. The sand could be replaced with mixed resins and the filter operated in the usual fashion. Modifications in piping would be required to permit regeneration of the resins with acid and base solutions. However, this use of the ion exchange method requires additional investigation to determine its merit.

5.2.7.2 Special Treatment - Conventional treatment or modified conventional treatment may produce a satisfactory water for emergency conditions. However, to render grossly contaminated water safe for consumption over an extended period, special treatment methods will be required. Distillation and post-ion exchange are the best methods presently available for treatment of large quantities of water. (Table 5.2). These methods are relatively expensive and require a detailed study of each water supply system to determine the type and capacity to be installed. They may serve as high-capacity permanent additions to a system, moderate-capacity mobile units or small-capacity emergency units.

a. Major Permanent additions to the Water System - It may be desirable in some systems to supplement conventional treatment facilities with permanent post-ion exchange or distillation units to treat all or some part of the usual output of a system. Of course, economic factors favor special treatment for only a small portion of the usual demand.

Considerable investigation has been conducted to determine the efficiency of distillation for desalinization of seawater. Vapor compression evaporation, one form of distillation, has also been found very effective for reducing radioactivity in water. The cost of treating water by this method, approximately $1.50 per thousand gallons, would make the cost of treating the entire peacetime demand prohibitive. However, the cost of providing distillation units to provide water for drinking and cooking only, does not seem excessive. For example, a distillation unit of this type with a capacity of 700,000 gallons per day would cost approximately $1,200,000. For a limited use of 2 gallons per person per day, the initial cost for equipment would be about $3.43 per person.

The operating cost of $0.0015 per gallon would not be a significant factor, except insofar as the availability of power or fuel is concerned.

The ion exchange process requires cation and anion resins in series or mixed beds. Various combinations of resins and regenerating solutions are available to meet specific needs. The basic unit is a cylindrical steel tank containing the resin. Water, usually under pressure, flows through the resins which are regenerated with acid and basic solutions stored in separate tanks. The flow rate is limited to about 5 gallons per minute per square foot of resins, but multiple units can be supplied to satisfy large demands. The cost of producing water using post-ion exchange is approximately 10 to 50 percent of the cost of distillation.

b. <u>Portable Special Treatment Units</u> - Portable or mobile ion-exchange or distillation units that could be deployed as required after a nuclear attack could be used to supply potable water in areas where ground water, stored water or other uncontaminated water is unavailable. Field tests using U.S. Army mobile purification units have indicated the effectiveness of one method of treating water contaminated with bomb debris (26). A 1500 gallon per hour truck-mounted water purification unit provided facilities for conventional coagulation, filtration and disinfection. Final treatment was provided by a 1500 gallon per hour truck-mounted ion exchange unit using separate bed, regenerative-type ion exchangers. This Corps of Engineers equipment reduced the level of contamination to below emergency Army drinking water tolerance. These units, working in series, could withdraw water from the distribution system or from streams or rivers, and provide a limited quantity of potable water for civilian use. The ion exchange unit could be attached to a fire hydrant to provide final treatment for water previously treated at a conventional municipal plant. These units could be located at intervals to permit inhabitants to walk to the unit and carry potable water home in containers of 1 to 5 gallon capacity.

Mobil truck-mounted distillation units could be used in a similar fashion to produce a high quantity potable water. Clever-Brooks Special Products, Inc. can manufacture a self contained 100,000 gallon per day vapor compression evaporator for $225,000. Units of this type could supply 2 gallons of potable water per day per person at an initial cost of about $4.50 per person. Of course sufficient quantities of fuel must be available for the operation of any portable or mobile unit.

c. <u>Small Capacity Special Treatment Units</u> - Small capacity ion exchange or distillation units that can be operated without special training might be used to advantage in some circumstances. Such units could be used during the shelter phase if a continuous inflow of water is assured. The ion exchange units could operate without power. During the post shelter phase, small capacity treatment units could serve to provide potable water if the public water supply system was inoperable for an extended period. Such units could also provide final treatment if the municipal plant could not produce a high quality water.

Throw-away cartridge type ion exchange units having a capacity of 5 gallons per hour can be obtained for approximately $15.00. The mounting fixture and wall bracket equipment for the cartridge costs about $20.00. A larger non-regenerative column type unit with a capacity of 50 gallons per hour costs $245.00, and each resin replacement costs $60.00. Radioactivity in the resin may make a throw-away unit preferable. In each of these units, a color change of the resin can be used to indicate when the cartridge should be discarded.

Small distillation units with capacities from 5 to 50 gallons per day that operate on standard 110 volt A.C. may be useful in some cases. Units that could be operated with fuel oil, gasoline or even wood may be preferable. The cost of electrical power to operate these units is approximately 5 cents per gallon. Of course, costs would not be a vital factor in an emergency necessitating the use of these units.

5.2.8 Distribution of Potable Water during the Post Shelter Phase

Scheme "F" described previously in section 5.1 utilizes potable water which is hauled and distributed to the public during the post shelter phase. Some specific means of accomplishing this are discussed in this section.

If transportation facilities have not been excessively damaged in an attack, it should be possible to haul enough pure water, say 2 gallons per person per day, over considerable distances. Bulk methods of hauling liquids such as tank cars, tank trucks and boats would be most suitable but in an emergency, trucks, buses, automobiles and aeroplanes could haul water in drums. Once water reached the community to be served it could be distributed to the public in several ways. Tank trucks filled with water could be stationed at convenient points in the community for dispensing of water to the public in bottles, cans, or other containers.

More elaborate procedures of distribution similar to home milk delivery methods could be used as conditions permit. Table 5.3 shows that approximately 32% of the retail price of milk is due to packaging and delivery costs. This indicates a cost of approximately

TABLE 5.3

COST OF MILK DISTRIBUTION IN NEW YORK STATE

Item	Percent of Total Cost
Packaging Materials	4.83
Processing labor (estimated as 1/2 of total)	2.73
Other processing costs (estimated as 1/2 of total)	1.98
Labor	12.47
Automobile	2.94
Officers Salaries	1.00
Other administrative salaries	1.61
Other administrative expenses	2.43
Operating profit	0.70
TOTAL	32.14

Reference (25)

eight cents per quart for packaging and delivery. The price of home delivery of water can be further reduced to approximately eight cents per gallon if the water is delivered in 55 gallon drums. Bulk delivery, similar to home fuel oil delivery, would offer still greater economy.

Appendix II offers a tabulation of estimated bulk rate haulage costs as compiled by Texaco, Inc. For a hauling distance of 100 miles, water could be delivered for approximately 2 cents per gallon. Such delivery by gasoline trucks has been effected in the past without apparent health hazard from the gasoline residue.

The approximate cost of various containers suitable for the storage of water is indicated in Table 5.4. A wide variety of containers are available to meet specific needs.

5.2.9 Spare Parts and Expendable Supplies

A most important consideration in the reduction of vulnerability of a water supply system is an adequate supply of spare parts. The quantity and type of equipment to be stocked depends upon the characteristics of the particular system and the estimated duration of emergency conditions. The large variety of equipment and manufacturers will probably require each system to provide for its own needs, although some centralized stock-piling of essential equipment will be possible.

Expendable supplies, particularly chemicals, may be depleted in a short time after an attack. While it would be difficult to store an adequate supply of chemicals used in large quantities, it is important that chemicals for disinfection, such as chlorine or chlorine compounds, be available for an extended emergency period. Disinfection will be particularly essential if it becomes necessary to curtail other conventional treatment.

5.2.10 Selective Withdrawal from a Reservoir -

Fallout deposited directly on the surface of a

TABLE 5.4

WATER CONTAINERS (27)

Capacity in Gallons	Description	Cost in cents per gallon stored
55	Aluminum drum.	109
55	Steel drums with lid and heavy polyethylene liner.	49
55	Steel drums with lid and thin (3 gauge) polyethylene liner. No sharp edges permitted inside of drum.	19
55	Blown plastic bottle with steel outer shell.	19
55	Standard weight cylindrical polyethylene tanks with lids.	46
55	Lightweight polyethylene drum in 24 gauge steel drum.	23
55	Lightweight polyethylene drum in fibre drum.	21
5	Plastic bottle with steel outer shell.	38
5	Plastic bag (U.S. Army).	20
5	Square tin plate can - 30 gauge.	12
5	Polyethylene drum.	60
5	Featherweight polyethylene drum in steel drum.	17
1	Plastic Bottle.	17
1/2	Plastic Bottle.	26
1/4	Plastic bottle.	32
1/4	Paper Milk Container.	4.0

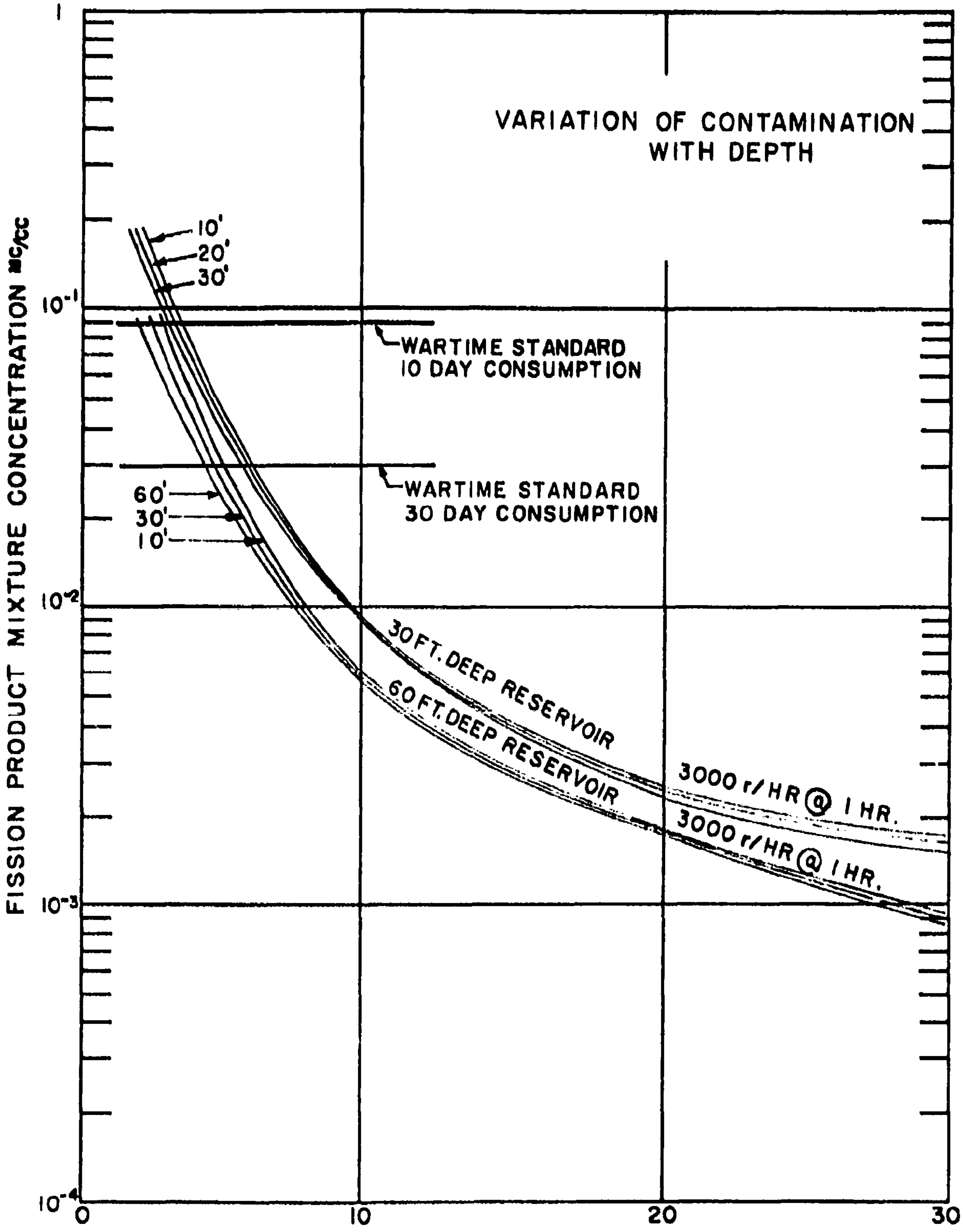
reservoir tends to mix with the water and contaminate the supply. The rate of mixing depends upon many factors including fallout material, size distribution, depth of reservoir, solubility and motion of the water. In some reservoirs it would be possible to draw off water at various elevations in order to select the water of highest quality. However, the advantages to be gained by this method are slight and of short duration. Figure 5.10 indicates the anticipated concentration of a 10% soluble clay-loam fission product mixture at various depths in a 30 ft. and 60 ft. deep reservoir. A surface concentration of 3,000 r/hr. at 1 hour (6×10^{15} fissions/sq. ft.) was used, but a similar set of curves can be drawn for any surface concentration.

Several conclusions can be drawn from an examination of the figure:

a. A deep reservoir will, in general, be less contaminated than a shallow reservoir.

b. There is a slight variation of contamination with depth in a reservoir. The variation decreases with the passage of time and is not significant after 5 days. This would indicate that selective withdrawal might be advantageous for the first few days after detonation, but relative contamination would still be high and, except for low fallout concentrations, the water would not meet minimum standards without further treatment.

Other assumptions as to fallout type, solubility, depth of reservoir and fallout intensity indicate similar trends. This theoretically indicates that selective withdrawal does not offer a significant advantage. However, actual radiological measurements in a reservoir may indicate some advantage in specific instances.



CLAY-LOAM FALLOUT ON RESERVOIR-10% SOLUBLE

FIGURE 5.10

SECTION 6

AVAILABILITY OF UNCONTAMINATED WATER

6.1 SOURCES OF SUPPLY

Even if the water supply becomes non-potable due to radioactive contamination or supply plant destruction, several important sources of water are available to a high percentage of the population. These sources, generally of limited supply, are significant on an emergency basis during the shelter phase and, in some cases, long afterwards. Arranged in order of desirability (because of yield and reliability) they are:

a. Wells.

b. Distribution system of water supply utility.

c. Building plumbing.

6.1.1 Wells

The advantages of an independent well water supply to shelter and post-shelter operation are obvious. Shelter capability would be greatly improved in such areas as extended occupancy, "button-up" periods and overcrowding. In the post-shelter phase these wells could provide water for fire control and decontamination as well as reduce the possible urgency in restoring of normal water supplies.

Potable well water is available in every state of the union albeit not necessarily in desired locations or quantities from a Civil Defense standpoint. In 1960, 46,600,000 people were served by public ground water sources as opposed to 87,400,000 served by public surface water supplies. The remaining 48,000,000 rural users of water (other than public supplies) withdraw 2,800 million gallons per day from wells and springs and only 850 mgd from surface supplies. (24)

Concurrent studies of the availability and quality of well water are being conducted by Guy B. Panero Inc. (28) Since these studies will deal in detail with the problems, costs and beneficial uses of developing ground water resources, further discussion of this source will be limited to the following broad potentials of quantity (16):

Single Wells of moderate depth and diameter in hard rock . . . . . . 1 to 50 gpm

Single Wells in coarse sand and gravel or sandstone . . . . . . .50 to 500 gpm

Single Wells in deep aquifers. . . .100 gpm or more

6.1.2 Distribution System of Water Supply Utility

This source represents what may be the most important supply of potable water immediately available to urban and suburban populations. Because these communities are normally served by elaborate distribution systems incorporating large storage reservoirs, significant quantities of water could be available under certain circumstances.

Estimates made by the Department of Commerce in 1955 projected to 1960 indicated that the public water utilities had in use 8,600 reservoirs with a total capacity of 39.4 billion gallons, - 40.7% as ground reservoirs, 13.5% as standpipes and 45.5% as elevated tanks. (19) There is apparently no existing data regarding the percentage of covered ground reservoirs. However, the majority of standpipes and nearly all of the elevated tanks are covered.

Withdrawal of water from those covered portions of the system which operate under a gravity head presents no special difficulties. However, extraction of water from pipes whose natural hydraulic gradient is lower than the desired points of withdrawal does present problems. The quantity of water to be expected from this source is similarly subject to speculation, principally due to uncertainty regarding leakage and technical characteristics of the system and the withdrawal methods. A study of the problem does indicate however that this source is both a significant and a practical one.

6.1.2.1 Withdrawal Methods - Several basic methods are available for extraction of water from the distribution system. Use of either one or any combination of them will be governed by the physical attributes of the particular system, as will be also the efficiency of withdrawal.

6.1.2.1.1 Natural Gravity Drainage - The original founding of cities and other sizable communities has historically been along lakes, shores and river valleys since these were sources of water and commercial transportation. With natural development this area tended to become a center of population, business and commerce, or what is now known as the "congested high value business district." Increases in size and population tended to form around these central locations, eventually becoming the suburban areas.

This development also fixed the relative elevations of the principal business districts at generally lower levels than those of the surrounding areas, since the water surface elevations would normally be near the lowest in the area.

The same situation seems to prevail in the location of suitable fallout shelters. As borne out in the recent federal fallout shelter surveys, those shelters with protection factors of 100 or more are most numerous and of larger capacity in the principal business district than in other parts of the city. Logically, this would be so since the larger and more substantially constructed buildings are located there. These circumstances lend themselves favorably to the concept of gravity drainage of the system to areas where water demand is likely to be highest.

Naturally hydraulic studies would have to be made to ascertain for any individual community the extent to which this theory applies, but it is felt that as a very general axiom it may be accepted.

At the present time a substantial percentage of the national population has a gravity flow distribution system.

A study was made of the central cities of the 70 most populated metropolitan areas having gravity flow (comprising 53,365 persons) to determine the time duration of water at 5 gallons per capita per day. (24) This demand was somewhat arbitrarily selected to include leakage. The results, shown in Table 6.1, include only existing facilities for the city proper. The possibility exists that surrounding urban areas might also be served from the same gravity sources.

This data cannot be interpreted as indicative of the emergency water supply availability, since the supply is generally uncovered and hence subject to radioactive contamination. However, it does indicate that a substantial percentage of the population is served by a gravity feed system - a factor favoring possible gravity draining of the distribution system.

6.1.2.1.2 Forced Flow - In cases where hydraulic head is not available for gravity drainage, forced flow might possibly be instituted at strategic locations. The practicality of this approach would of course have to be determined on the basis of each individual water system and compared with costs of developing other water sources. While the scope of this study precludes a detailed investigation into the methodology of forced flow techniques, the following data are presented for illustrative purposes.

Two of the more conventional techniques which merit consideration are pumping and pressurizing with compressed air. Pumping by provision of an appropriate type of pump at the low points in the piping system is probably the less costly of the two. Table 6.2 compares several possible choices of mechanically operated pumps. Of course, manual pumping by such devices as

TABLE 6.1

SURVEY OF 70 MOST POPULATED WATER DISTRICTS TO DETERMINE AVAILABILITY OF GRAVITY FLOW OF DISTRIBUTION FACILITIES (20)

Minimum Days Supply at 5 GPCD	Population	Percent of Total	Cumulative Population	Cumulative Percentage
more than 50	9,181,400	17.2	9,181,400	17.2
25-50	6,072,400	11.4	15,253,800	28.6
15-25	2,629,000	4.9	17,882,800	33.5
10-15	3,568,000	6.8	21,450,800	40.3
5-10	11,606,500	21.7	33,057,300	62.0
1-5	5,906,800	11.0	38,964,100	73.0
more than 0-1	9,392,500	17.4	48,356,600	90.4
none	5,008,800	9.6	53,365,400	100.0

TABLE 6.2

COMPARISON OF PUMP CHARACTERISTICS (30)

Type of Pump	Reciprocating, Plunger or Piston	Rotary	Centrifugal
Displacement	Positive	Positive	Non-overloading
Priming Requirements	Self-priming	Self-priming	Non (1) priming
Suction Lift Max. (ft.) (2)	22	22	15 (3)
Head	High	Medium	Low to Medium
Use with Water	Good	Poor (4)	Good
Pump Relief	Required	Required	Not required
Capacity Range	Small	Small to Medium	Any Capacity
Reaction to Positive Suction Head	Poor	Poor	Good
Equipment Cost	High	Low to Medium	Low
Maintenance Cost	High	Low	Low

(Continued)

TABLE 6.2 - (Continued)

NOTES:

(1) Gravity or outside source of priming required, such as:

  a. By Hand.

  b. By Compressed Air.

  c. By a Double Tank; or two Compartment System.

  d. By Vacuum Pump (Manual or Automatic).

(2) At sea level; reduces approximately 1 ft. for each 1,000 ft. of elevation.

(3) Or no more than 2/3 total operating head.

(4) Rotary pump usually used with a self-lubricating liquid such as oil. With water, metal to metal contact would result in undue or rapid wear.

the pitcher pump could also be used in specific applications. This pump, connected to a main and primed from within a shelter, could deliver as much as 2,400 gallons per day at 30 strokes per minute.

Compressed air might be used to build up pressure and force water out in a method similar to hydro-pneumatic systems used in buildings. This method, however, could not extract water which would not normally flow by gravity. Its purpose is to build up pressure for more rapid or efficient use.

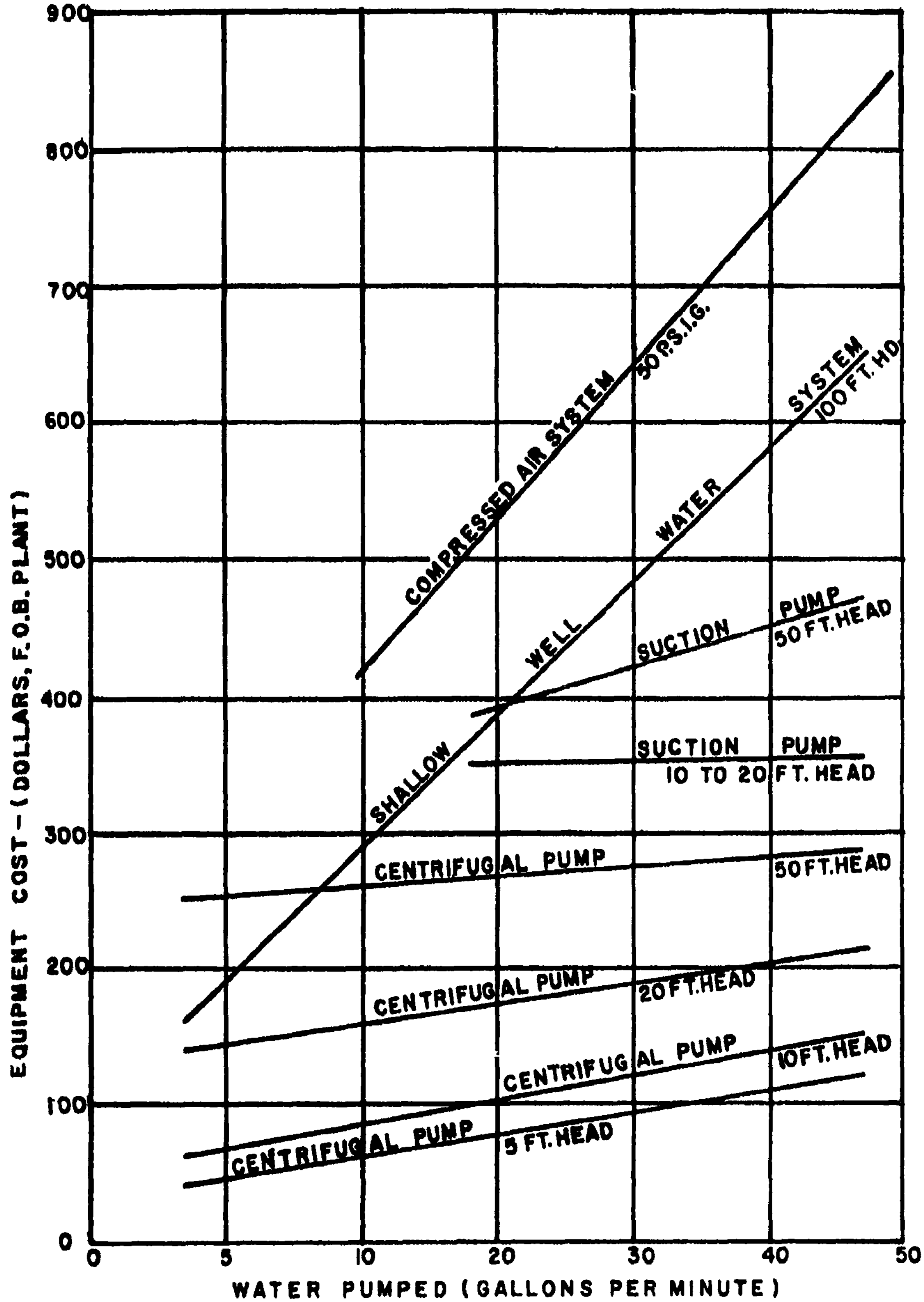
A cost comparison of various pumps and of a compressed air installation is given in Figure 6.1.

6.1.2.2 Anticipated Quantities - The amount of water to be anticipated from the distribution system is dependent upon a number of factors. The volume and hydraulic gradient of the piping system, capacity of covered water storage, pipe leakage rate and water use such as for fire fighting or decontamination are all factors which significantly affect water quantity. Some of the parameters can of course be ascertained from the system itself, such as capacity of covered water storage and pipe volume. Other factors will never be really known in advance since they are so directly related to the post-attack situation. These include pipe breakage or use of water for fire fighting, decontamination, etc. Leakage, while subject to great variation can be estimated at least closely enough to permit a planning spectrum of loss.

In a gravity draining system the normal leakage will lessen as the pressure is reduced and as the pipes are emptied of water. As long as the distribution piping is flowing full this leakage (primarily due to joint looseness) can be related to pressure as shown in Figure 6.2. The curve is based upon the relationship:

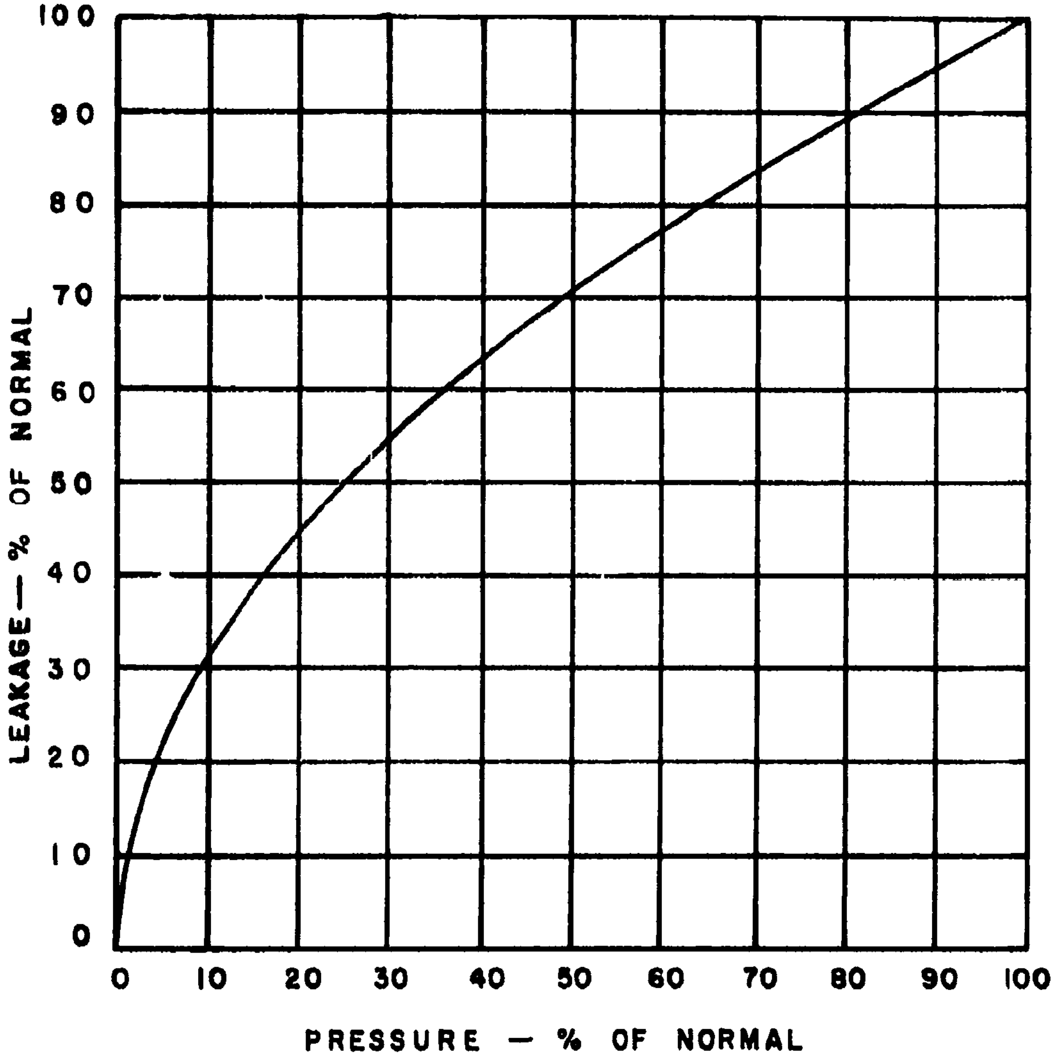
$$L = KP^{\frac{1}{2}}$$

where L = leakage (Gallons per day per capita)
p = gauge pressure of pipes (psi)
K = a constant



EQUIPMENT COSTS OF PUMPING WATER

FIGURE 6.1



RELATIONSHIP OF LEAKAGE TO PRESSURE

FIG. 6.2

However, if the system contains elevated storage tanks or standpipes, this relationship will change as soon as these tanks have been emptied, and water is drawn only from the piping. This is due to the fact that as water is drawn from the lower points, those pipes with higher inverts begin to empty or flow only partially full. As the number and length of pressurized joints decreases, the amount of potential leakage also decreases. The exact relationship by which this decrease occurs is difficult to estimate since it is so closely correlated to the layout and hydraulic gradient of the system itself, and the points of water demand (including more than normal leakage points). A study of any particular system would probably result in an empirical relationship including pressure and number and diameter of joints. However, in lieu of the type of detailed information required, a general and conservative estimate might be made by assuming the leakage to be directly proportional to the volume of the unused water in the piping system.

The following simplified examples serve to illustrate how these relationships might be used to estimate the time duration of the water available from the distribution system if certain characteristics of the system were known.

A hypothetical community of 25,000 population is taken with the following water data:

Elevated storage - 20' dia x 20' high tank mounted on a 30' high standpipe. Capacity - 47,000 gals. (See Figure 6.3)

Volume of distributinn piping - 1,000,000 gals.

Average leakage - 7 gal. per capita per day.

Average street main pressure - 50 psi

Emergency consumption - 1 gal. per capita per day.

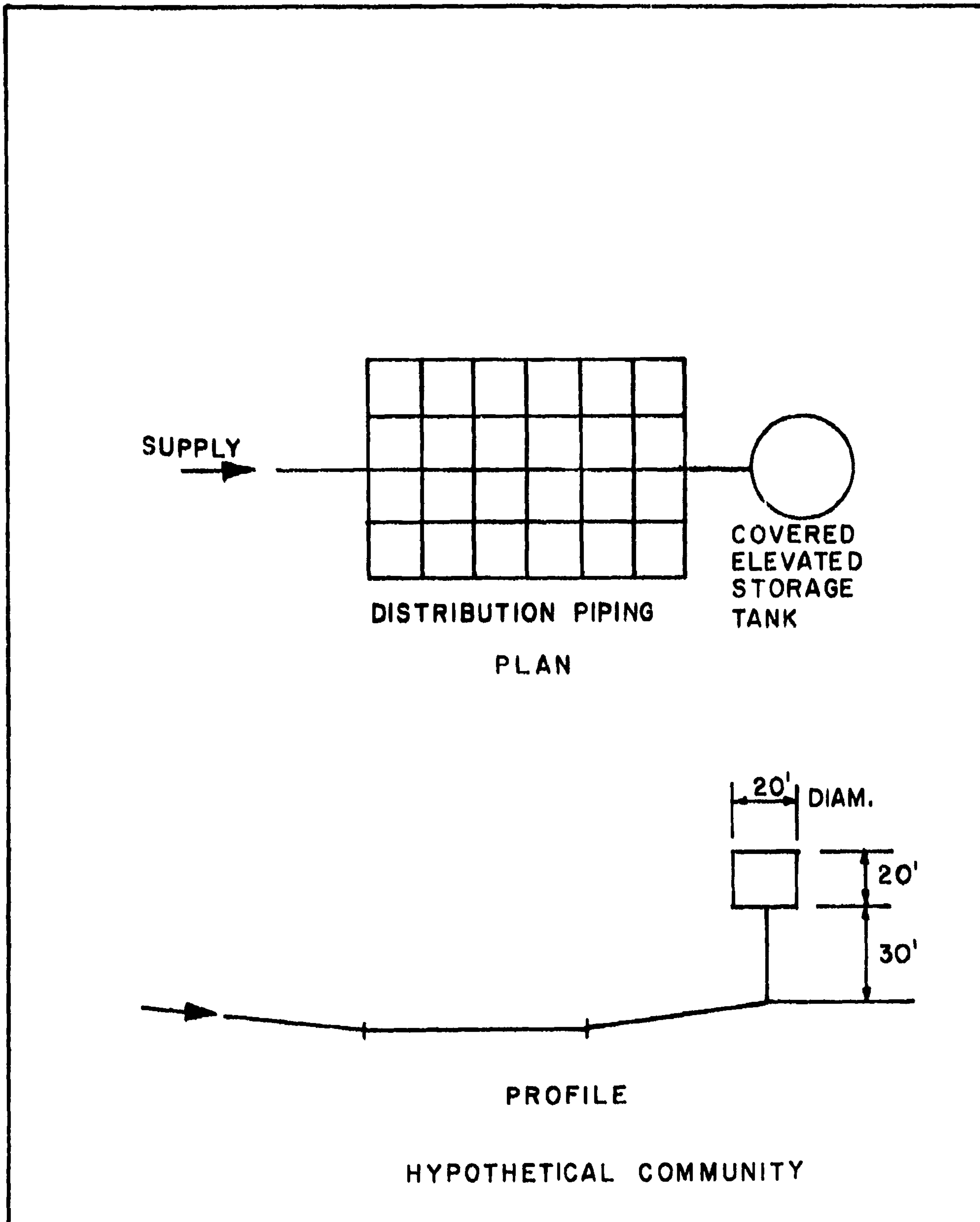

SUPPLY
COVERED
ELEVATED
STORAGE
TANK
DISTRIBUTION PIPING
PLAN
20'
DIAM.
20'
30'
PROFILE
HYPOTHETICAL COMMUNITY

FIGURE 6.3

Two cases are considered:

Case I - The entire system drains by gravity to the demand source.

Case II - 70% of the distribution system is non-recoverable due to loss of hydraulic head when the elevated storage supply is depleted.

CASE I

With the foregoing assumptions, a history of the time-demand relationship can be drawn as shown in Figure 6.4. The portion of the curve marked "A-B" represents the demand (leakage plus consumption at 1 gallon per capita per day) while the tank is being emptied. Here leakage may be expressed in terms of pressure:

$$L = (KP)^{\frac{1}{2}}$$

K is obtained by using initial conditions.

$$K = \frac{L}{p^{\frac{1}{2}}} = \frac{7.0}{50^{\frac{1}{2}}} = 0.99$$

$$L = 0.99\ p^{\frac{1}{2}}$$

where L = leakage per capita per day
p = average pipe pressure

Time and Pressure are related as follows:
Change in tank volume = (Leakage + Consumption) x Population x (Change in Time)

or

$$dV = (0.99\ p^{\frac{1}{2}} + 1) \times 25{,}000) \times (dt) \qquad (1)$$

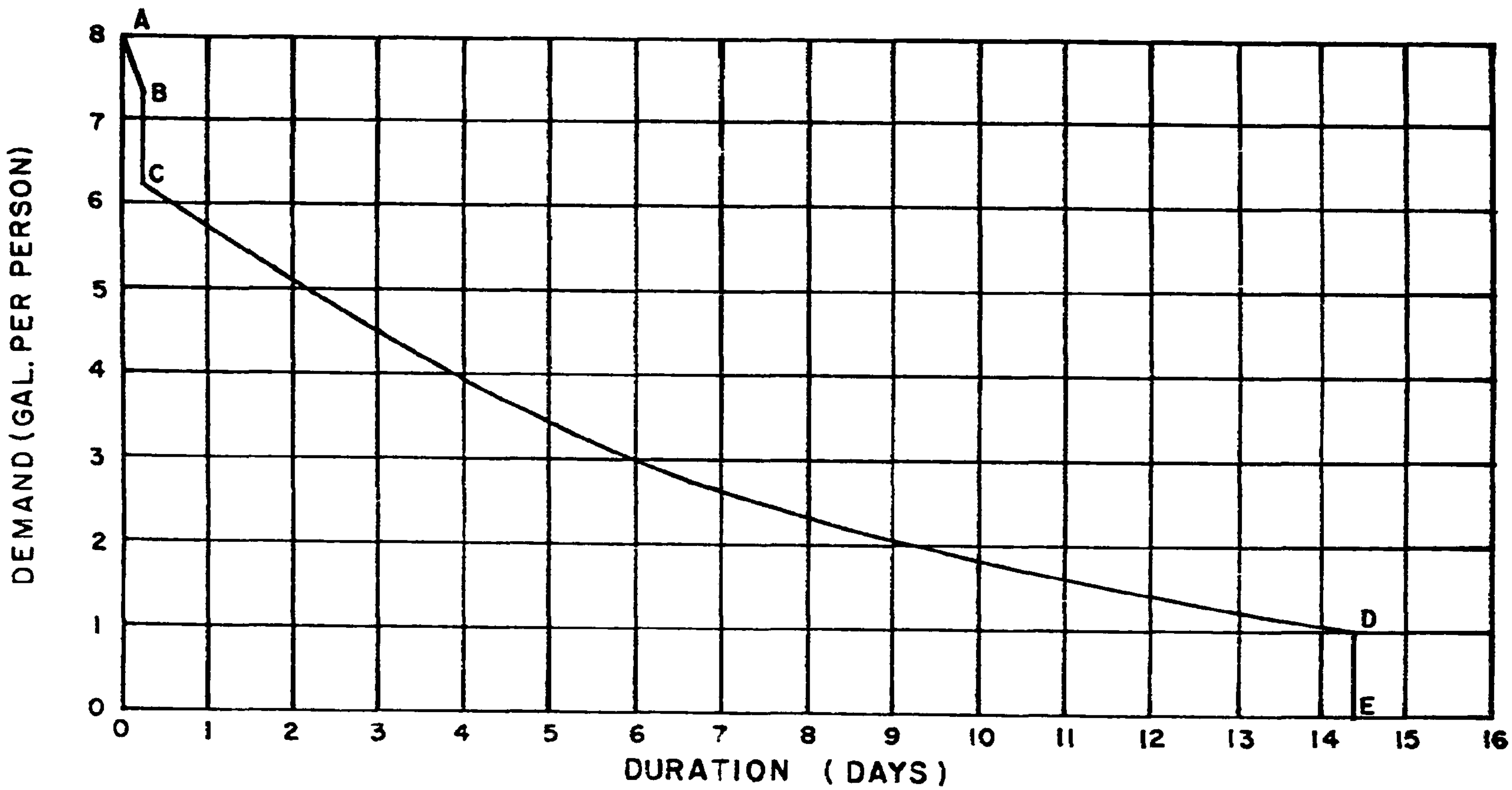
where t = Time in days
V = Volume of water in tank.

Pressure and Tank Volume can also be related as follows:

$$V_{\text{(gallons)}} = (\quad r^2) \quad (7.48) \quad H$$ where H = height of water in tank

$$V = 2350\ H$$

$$P = 50 - \frac{(20 - H)}{2.31}$$



EXAMPLE I-100 % UTILIZATION OF WATER IN DISTRIBUTION SYSTEM

F G 64

$$P = 50 - \frac{(20 - V/2350)}{2.31}$$

or $$P = 41.4 + V/5430 \qquad (2)$$

Substituting into (1) yields:

$$dV = 0.00 \quad (41.4 + \frac{V}{5430})^{1/2} + 1 \quad 25{,}000\ dt$$

Integrating,

$$25{,}000\ T = 6.52 \times 10^4 - 1.1 \times 10^4\ (1 + (40.8 + 1.81 \times 10^{-4} V^{1/2})$$

$$- \text{Ln}\ \ 1 + (40.8 + 1.81 \times 10^{-4} V)^{1/2}$$

Setting V = 0, the time duration of the tank storage is found to be 0.28 days. (If no leakage was to be considered, the supply would last 1.88 days at 1 gallon per capita per day).

The portion "B-C" of the curve represents a rapid drop in pressure (and consequently in leakage) due to the depletion of the water in the standpipe. The volume of water contained here is negligible compared to the demand and so the time duration is negligible and may be represented as a vertical line on the curve.

At "C", the pressure remaining in the system is reduced from the original by 50 ft. to 28.4 psi, corresponding to a leakage of 5.28 gpcd.

From "C" to "D", representing water storage in the pipe system, the total demand at any time "T" is:

$$\text{Demand} = (\frac{5.28V}{10^6} + 1)\ 25{,}000$$

since $V = (\text{demand})\ (\ \ t)$,

$$dV = (25 \times 10^3 + 0.132V)\ dt$$

$$T = 90.5 - 7.57\ \text{Ln}\ (25 \times 10^3 + 0.132V)$$

When the pipes are emptied, V = 0 and T = 14.1 days.

This time is additive to the elevated storage duration giving a total minimum time duration of 14.38 days.

CASE II (70% loss of distribution piping supply)

As shown in Figure 6.5, the portion of the demand-duration curve from "A" to "C" is the same as for Case I. The drop in demand from "C" to "D" represents a 70% reduction in the leakage portion due to non-recovery of 70% of the water volume. The remaining portion of the curve from "D" to "F" is determined as shown for Case I.

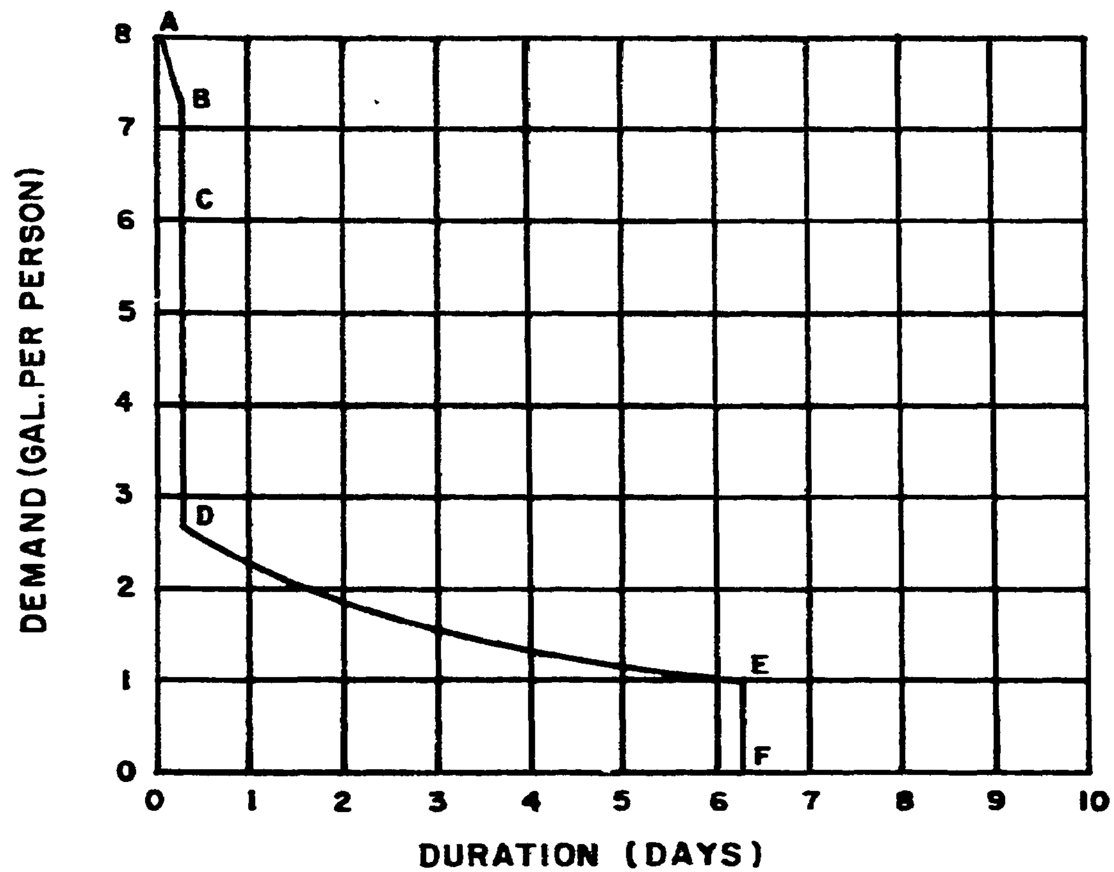
6.1.2.3 25 City Survey - In an attempt to arrive at some quantative estimate of the water actually available in the national distribution networks, a study was made of 25 cities of over 25,000 population.

These cities were selected more or less at random to represent a nationwide cross-section sampling; both in size and geographically. They range in population from Middletown, Ohio (25,750) to Chicago (4,690,000).

Sixteen of the cities are under 300,000 population; four between 300,000 and 1,000,000; and five over 1,000,000. The combined population of all 25 cities is 18,300,000, which represents 10% of the present national population; 15% of the present urban population and 20% of the urban population in communities of 25,000 or more receiving treated water.

The cities surveyed and their respective populations are given in table 6.3 and geographically located in Figure 6.6.

It should be noted that the population data in the table represents the water population served on the date indicated. While most of this information is recent, data on some cities dates back to the late 1940's and early 1950's. Since the water supply systems, as well as the population of any city, are in a state of constant change, it was felt that no significant inaccuracies would result from use of this data. The effect of this assumption in extrapolating the results is to presume that the rate of population change is



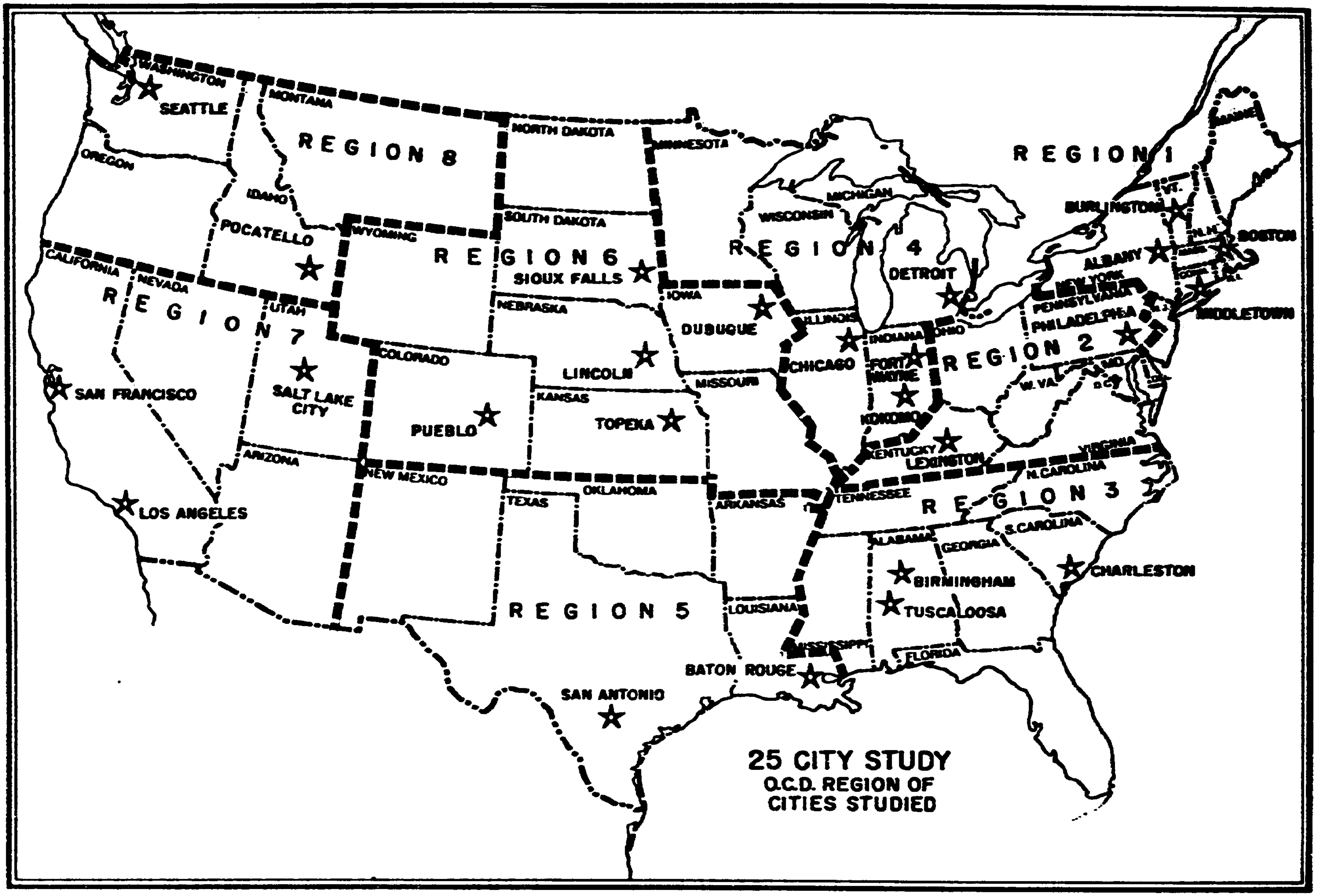
EXAMPLE II - 30 % UTILIZATION OF WATER IN DISTIBUTION SYSTEM

FIG. 6.5

TABLE 6.3

25-CITY SURVEY

OCD Region	Cities Surveyed	Water Population Served at Date Indicated	Date of Survey
1.	Burlington, Vt.	45,000	1954
	Albany, N.Y.	142,000	1958
	Boston, Mass.	801,500	1951
	Middletown, Conn.	25,750	1954
2.	Philadelphia, Pa.	2,250,000	1956
	Lexington, Ky.	120,000	1955
3.	Birmingham, Ala.	508,500	1959
	Tuscaloosa, Ala.	71,000	1957
	Charleston, S.C.	150,000	1955
4.	Detroit, Mich.	3,199,500	1953
	Chicago, Ill.	4,690,000	1961
	Fort Wayne, Ind.	151,000	1960
	Kokomo, Ind.	55,000	1953
5.	Baton Rouge, La.	250,000	1957
	San Antonio, Texas	408,500	1952
6.	Sioux Falls, S.D.	70,000	1958
	Lincoln, Neb.	130,000	1958
	Pueblo, Colo.	118,000	1960
	Topeka, Kansas	126,000	1959
	Dubuque, Iowa	58,000	1956
7.	Salt Lake City, Utah	272,200	1954
	San Francisco, Cal.	1,500,000	1951
	Los Angeles, Cal.	2,426,000	1947
8.	Seattle, Wash.	724,000	1959
	Pocatello, Idaho	30,000	1955



25 CITY STUDY
O.C.D. REGION OF
CITIES STUDIED
REGION 1
REGION 2
REGION 3
REGION 4
REGION 5
REGION 6
REGION 7
REGION 8
SEATTLE
SAN FRANCISCO
LOS ANGELES
POCATELLO
SALT LAKE CITY
PUEBLO
SIOUX FALLS
LINCOLN
TOPEKA
SAN ANTONIO
DUBUQUE
CHICAGO
DETROIT
FORT WAYNE
KOKOMO
LEXINGTON
BATON ROUGE
BIRMINGHAM
TUSCALOOSA
CHARLESTON
PHILADELPHIA
ALBANY
BURLINGTON
BOSTON
MIDDLETOWN
WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
ARIZONA
COLORADO
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
MICHIGAN
ILLINOIS
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
S.CAROLINA
N.CAROLINA
VIRGINIA
W.VA
MD
D.C.
NEW YORK
PENNSYLVANIA
N.J.
VT.
N.H.
MAINE

FIGURE 6.6

coincident with the rate of change in the water distribution system. This presumption is not altogether unwarranted since water supply systems tend to keep up with population changes and, while there is a natural lag, the trend is generally upward in both cases.

Each city was studied to determine:

a. The amount of treated water stored in covered reservoirs, either:

(1) Elevated storage immediately available to shelter locations by gravity flow.

(2) Ground storage that must in most cases be pumped to be made available.

b. The amount of water represented by the volume of the distribution system.

This data is summarized in Table 6.4 and represents a maximum water availability of the system. In order to translate this data into an estimated supply several assumptions were made:

a. Except for leakage, the total amount of covered storage (both above and below ground) could be made available. This presumes that pumping would be instituted at those below ground reservoirs where static head is not available for gravity flow. Loss of this water through leakage is estimated at 5%. This figure derives from the American Water Works Association and other sources which indicate that "unaccounted for" water averages about 15% of the normal peacetime demand (31). This includes unrecorded fire hydrant losses, low flows not registered in meters, supply to unmetered sources and leakage. One third of this loss, or 5%, is considered to be the average leakage portion. Table 6.5 shows, for each city studied, the daily demand and the estimated leakage at 5%.

b. Of the total water contained in the distribution system, only 30% would be recoverable

TABLE 6.4

25 CITY SURVEY

SUMMARY OF TREATED WATER AVAILABILITY (22)

City	Total Volume of Distribution Sys. (Gallons)	Total Volume in Elevated Covered Storage (Gallons)	Total Volume in Below Ground Covered Storage (Gallons)	Main Source of Supply
Boston	99,645,000	4,800,000	2,000,000	Rivers, impounded
Albany	8,750,000	150,000	2,000,000	Creeks, impounded
Middletown	1,545,000	1,000,000	-	Brook reservoirs
Philadelphia	125,000,000	1,000,000	123,300,000	Rivers
Pueblo	4,360,000	1,150,000	-	River
Detroit	148,000,000	10,500,000	126,000,000	River
Lincoln	5,580,000	3,260,000	30,600,000	Wells
Birmingham	22,650,000	1,140,000	3,500,000	Lakes, river
Salt Lake City	11,900,000	2,350,000	-	Creeks, impounded Aux. wells
Seattle	28,590,000	13,800,000	-	River; Lake Storage
Dubuque	1,660,000	1,350,000	10,570,000	Wells
Pocatello	853,000	600,000	-	Wells, creeks
Topeka	2,940,000	1,000,000	13,000,000	River; wells
Lexington	1,290,000	1,500,000	1,300,000	River, impounded
Sioux Falls	1,790,000	2,150,000	5,000,000	Wells
Chicago	80,000,000	-	32,600,000	Lake Michigan

(Continued)

TABLE 6.4 - (Continued)

City	Total Volume of Distribution Sys. (Gallons)	Total Volume in Elevated Covered Storage(Gallons)	Total Volume in Below Ground Covered Storage (Gallons)	Main Sourc of Supply
San Antonio	9,100,000	6,460,000	-	Wells
Burlington	974,000	210,000	100,000	Lake
Tuscaloosa	1,390,000	1,800,000	1,300,000	Creek, impounded
San Francisco	24,000,000	2,700,000	191,440,000	Lakes,Rive Wells
Fort Wayne	2,355,000	2,050,000	19,260,000	River
Kokomo	760,000	1,100,000	870,000	Wells & Emergency Surface
Charleston	1,490,000	2,450,000	12,000,000	River;cree impounded
Baton Rouge	2,430,000	2,400,000	7,850,000	Wells
Los Angeles	148,700,000	17,280,000	164,550,000	Wells,rive

TABLE 6.5

25 CITY SURVEY

AVERAGE DAILY DEMAND AND ESTIMATED LEAKAGE

City	Average Daily Demand (32)		Leakage	
	mgd	gpcd	mgd	gpcd
Boston	116.0	145	5.8	7.25
Albany	24.5	173	1.23	8.65
Middletown	2.18	85	0.11	4.25
Philadelphia	524.0	232	26.2	11.60
Pueblo	16.0	136	0.80	6.80
Detroit	477.0	149	23.85	7.45
Lincoln	22.15	171	1.11	8.55
Birmingham	41.8	82	2.09	4.10
Salt Lake City	58.7	216	2.94	10.80
Seattle	102.7	142	5.14	7.10
Dubuque	4.2	72	0.21	3.60
Pocatello	6.9	230	0.35	11.50
Topeka	12.17	97	0.61	4.85
Lexington	13.14	110	0.66	5.50
Sioux Falls	9.2	131	0.46	6.55
Chicago	1033.0	221	51.65	11.05
San Antonio	72.7	178	36.4	8.90
Burlington	3.4	75	0.17	3.75
Tuscaloosa	9.0	127	0.45	6.35
San Francisco	166.1	111	8.30	5.55

TABLE 6.5 - (Continued)

City	Average Daily Demand (32)		Leakage	
	ngd	gpcd	Mgd	gpcd
Fort Wayne	20.82	138	1.04	6.90
Kokomo	7.7	140	0.39	7.00
Charleston	15.0	100	0.75	5.00
Baton Rouge	14.81	59	0.74	2.95
Los Angeles	466.0	193	23.3	9.65

Average loss - 7.0 gpcd

by draining the system. Non-recoverable water is presumed to be due to:

(1) Leakage

(2) Relationship of the hydraulic gradient of the system to the elevations of drain connections to the shelters or of other emergency central water supply locations.

The resulting water availability, plotted against cumulative population percentage, is shown in Figures 6.7, 6.8 and 6.9. Demand rates of 0.25 and 1.0 gpcd are shown.

These curves show for any given percentage of the population the minimum days supply from:

a. The water distribution piping.

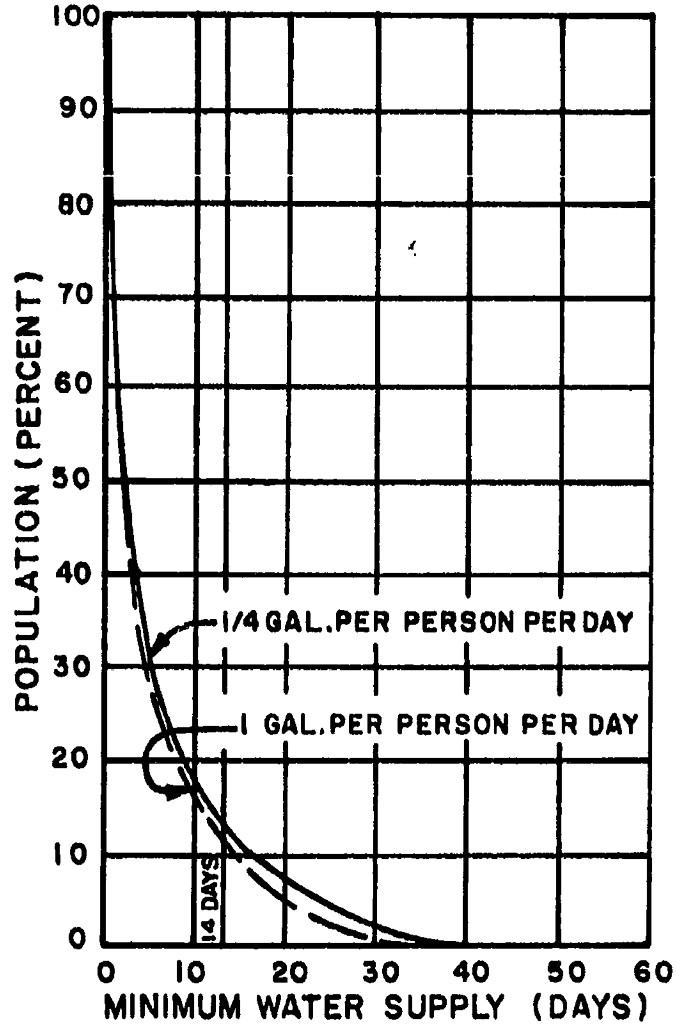
b. Covered storage (both below ground and elevated)

c. The combined total of (a) and (b).

It can be seen that the distribution system represents an important source of water during both the shelter and post-shelter phases. Statistically speaking, 100% of the population surveyed has a potential 17-day minimum supply of drinking water (at 1 quart per person per day), 71% has a 30-day minimum supply and 48% has a 60-day minimum supply, without replenishment of water to the system.

The significant portion of this supply is the water contained in the distribution piping which accounts for approximately 95% of the shelter phase supply.

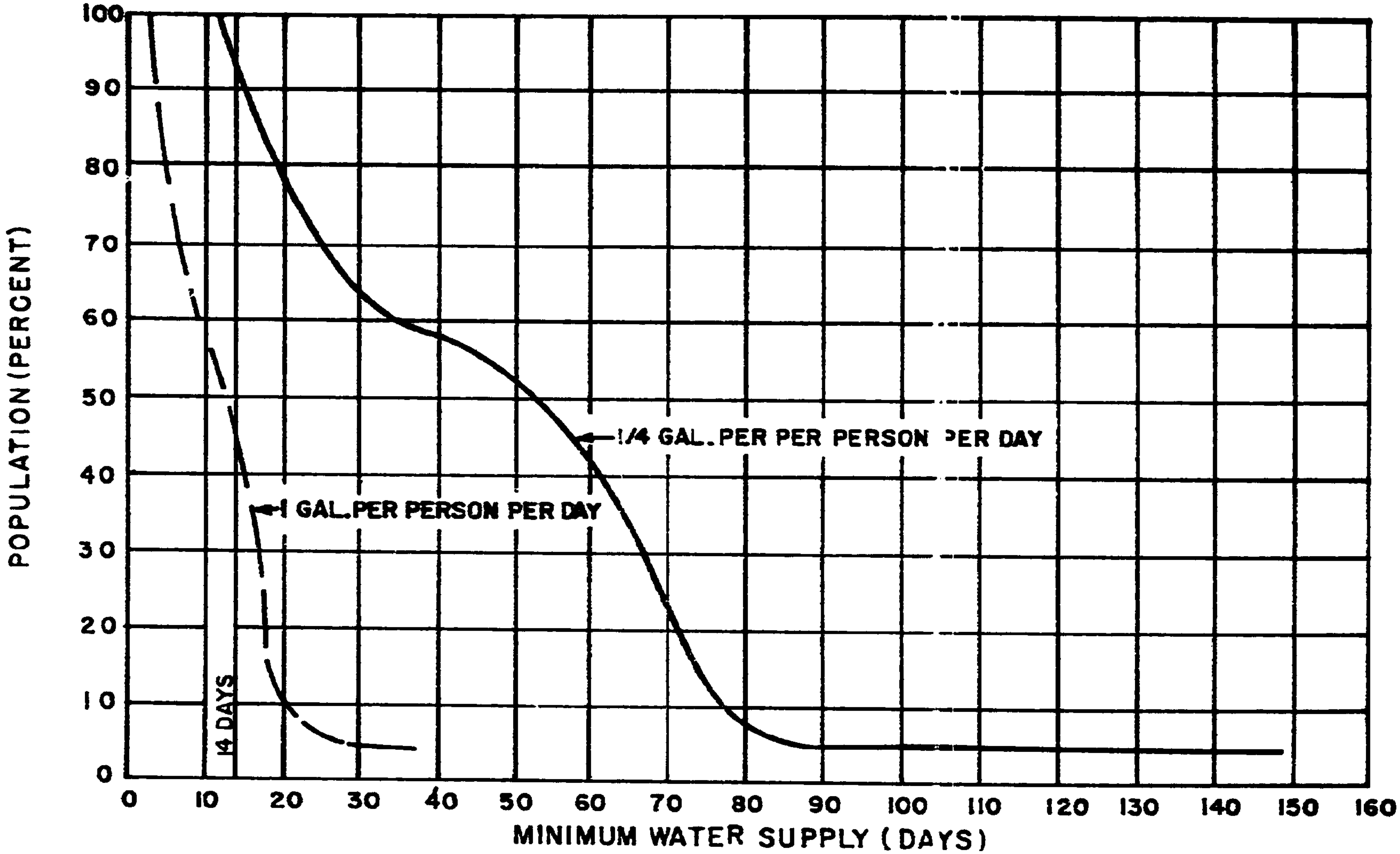
This relationship is, of course, sensitive to the recoverable quantities of water in both piping and covered storage. If, for example, all the covered storage supply could be utilized, (such as by local distribution rather than by pipes), the water supply would last 200% to 400% longer than by considering 5% leakage of this source. That leakage is the major cause of depletion of this supply is evident from Figure 6.7 which shows that the minimum duration of



25 CITY SURVEY

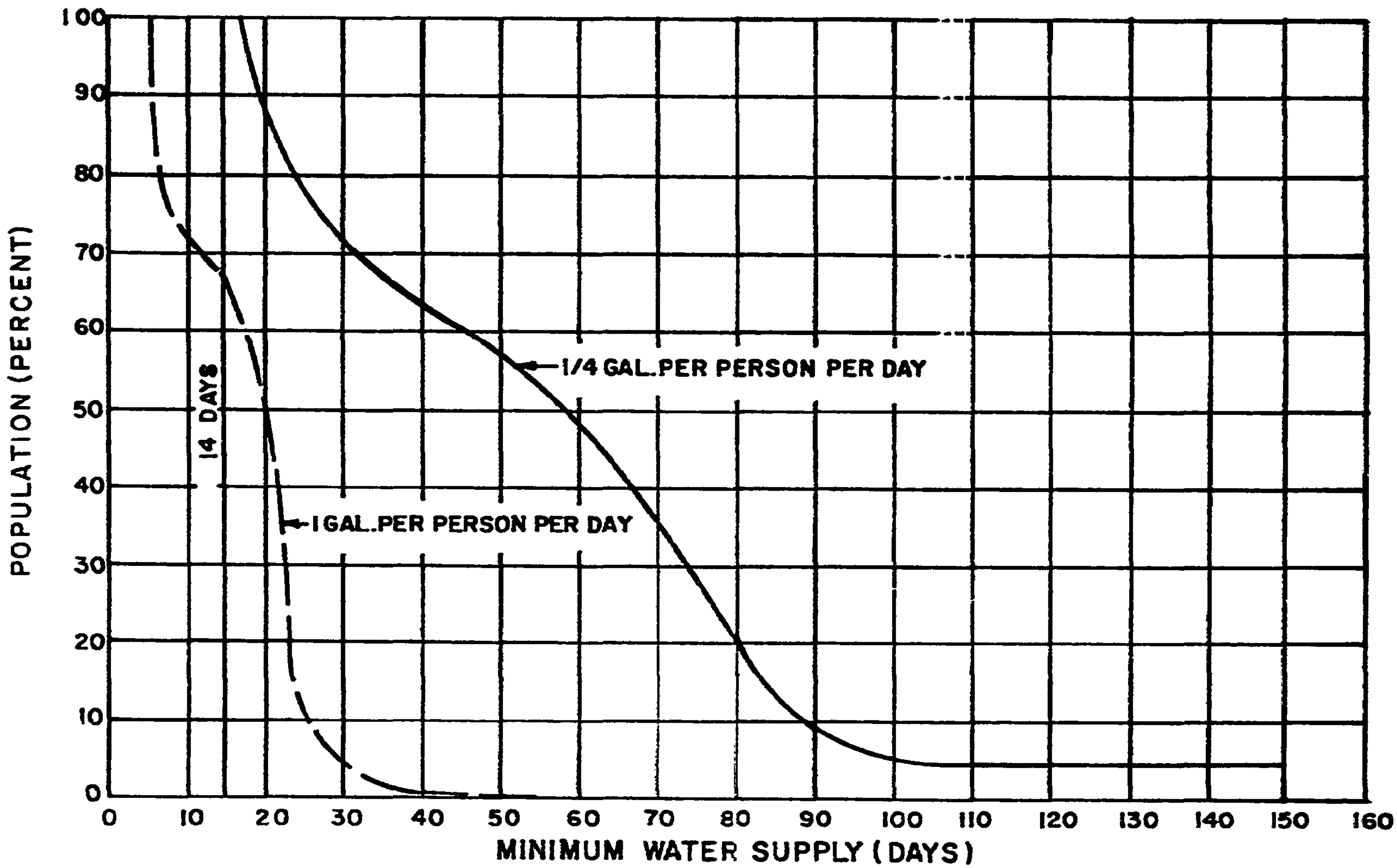
MINIMUM WATER SUPPLY IN COVERED STORAGE

FIGURE 6.7



25 CITY SURVEY
MINIMUM WATER SUPPLY-DISTRIBUTION PIPING

FIGURE 6.8



25 CITY SURVEY

TOTAL MINIMUM WATER SUPPLY IN COVERED STORAGE AND DISTRIBUTION PIPING

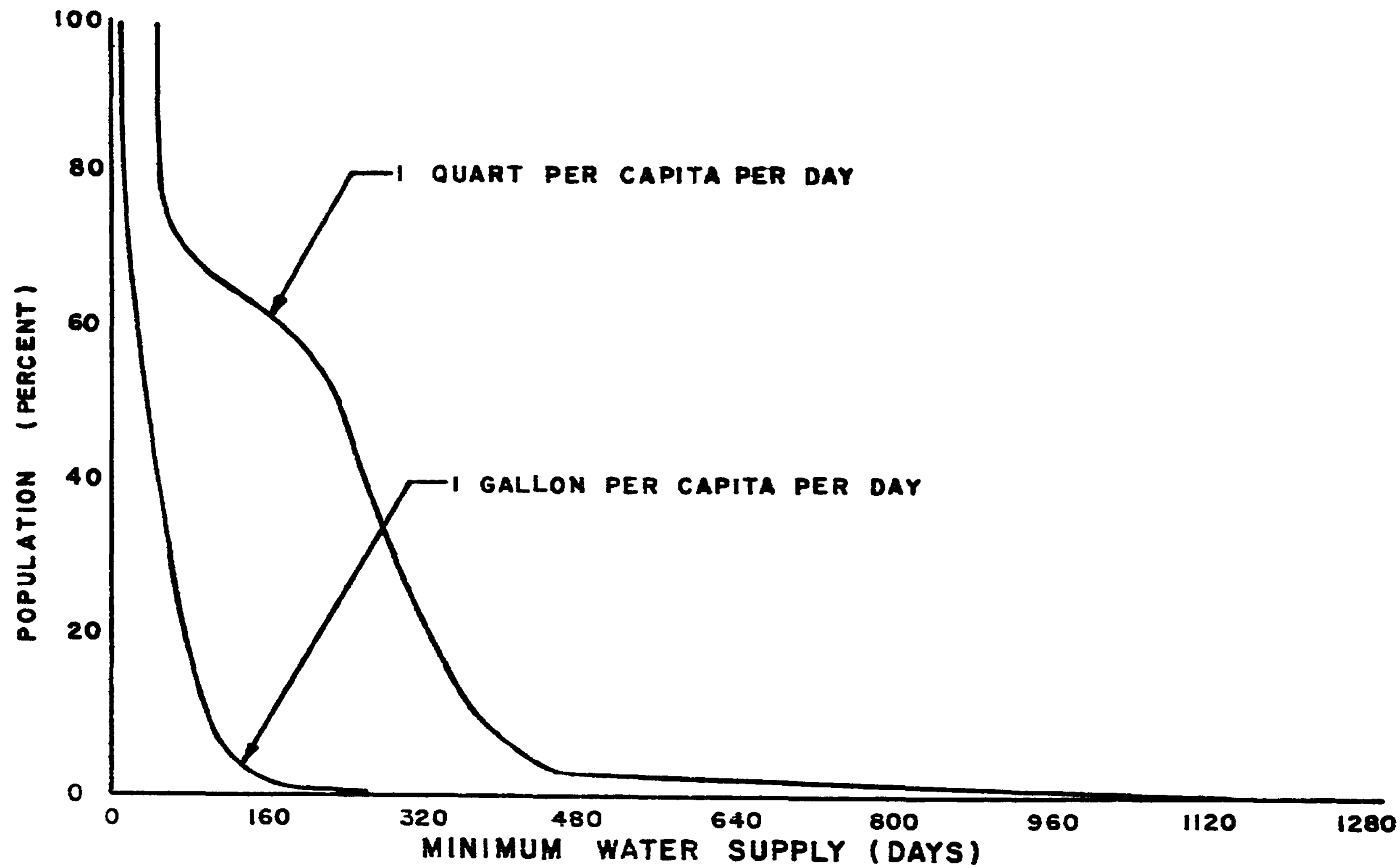
FIGURE 6.9

covered storage at 1/4 gallon per person per day is essentially unchanged even at the quadrupled rate of 1 gpcd. Figure 6.10 shows the estimated minimum duration of the total supply if 100% of the stored water and 30% of the distribution pipe water were recoverable at the consumption rates of 1 quart per capita per day and 1 gallon per capita per day respectively.

Of course, these conclusions must always be tempered with the fact that water used for other than the minimum survival quantities given will have profound effects upon the estimated duration. Use of water for decontamination or fire fighting, or loss due to breaks or other waste will substantially reduce or even negate the quantities estimated herein.

6.1.3 Building Plumbing - Significant quantities of potable water may be made available by draining the interior tanks, equipment and water piping of buildings. Naturally the quantity depends upon the type of equipment, usage, and extent of plumbing. The potability is affected by the possible use of chemical additives such as rust and algae inhibitors in water cooling systems, and disinfectants in swimming pools. Fire systems which are generally piped independently of the domestic water system contain non-circulatory water which may have been standing for years, and may subsequently be non-potable. This is particularly true of wet pipe sprinkler systems and fire standpipes, although the fire reserve in combined fire-domestic house gravity tanks is normally potable.

Non-potable water can be of important use in a fallout shelter. Again depending on its characteristics, it might be used for washing, heating contained foods (not cooking), sewage ejection, decontamination, make-up for diesel generator water jackets, etc. If predetermined as to effectiveness and quality, it might even be treated with disinfecting agents and used as potable water.



25 CITY SURVEY

MINIMUM WATER SUPPLY UTILIZING 100 PERCENT OF COVERED STORAGE AND 30 PERCENT OF DISTRIBUTION SYSTEM.

FIGURE 6.10

While it is impossible to categorically estimate the amount of water to be anticipated from these sources without a detailed study of the individual building, it would be a serious mistake to minimize its significance. In New York City, for example, the "average" house gravity tank capacity is about 15,000 gallons. At the minimum survival demand of 3-1/2 gallons per person per 2-week shelter period, this source alone would suffice for about 4,300 persons. An 8-inch riser pipe for a 20-story building contains another 700 gallons - sufficient for 200 persons at minimum demand.

It may be conservatively generalized that the larger the building, the more the availability of potable water from equipment and piping, and equally important, the greater the likelihood of suitable shelter from fallout. If the quantity could be determined, this water source might reduce or obviate the necessity of stored water in such shelters, thereby eliminating some of the problems of locating storage space, excessive floor loading and spoilage of stored water.

Potential sources of water within buildings are listed in table 6.6 according to anticipated potability. Many of them have already been investigated by the Office of Civil Defense and other agencies to estimate the amounts expected therefrom. To corroborate and extend these findings, a study was made of what appears to be the three prime sources of potable water:

a. House gravity tanks.

b. Water piping.

c. Hot water storage tanks.

6.1.3.1 House Gravity Tanks - These tanks are used when the height of the building is such as to exceed the pressure in the city main, or to provide a fire reserve. They are so located as to insure a minimum pressure at the uppermost fixture of about 10 psi. Sometimes, as in the case of high buildings, zone tanks are installed at intermediate levels so as to reduce

TABLE 6.6

POTENTIAL WATER SOURCES WITHIN BUILDINGS

Potable	Generally Non-potable	Must be Checked for potability
Domestic Suction Tank	Snow Melting System	Fire Standpipe Riser
House Gravity Tank	Hydraulic Elevator Water Tank	Sprinkler System
Hydro-Pneumatic Tank		Heat Exchanger
Chilled Water Drinking Systems		Well
Flush tank Toilets		Hot Water Generator Heating Medium
Hot Water Storage Tank		Steam Heat System
Piping System		Hot Water Heating System
		Radiant Heating System
		Chilled Water System
		Pools
		Water Cooling jackets for mechanical equipment.

the static pressure on the lower fixtures. The amount of water stored is a function of various parameters including:

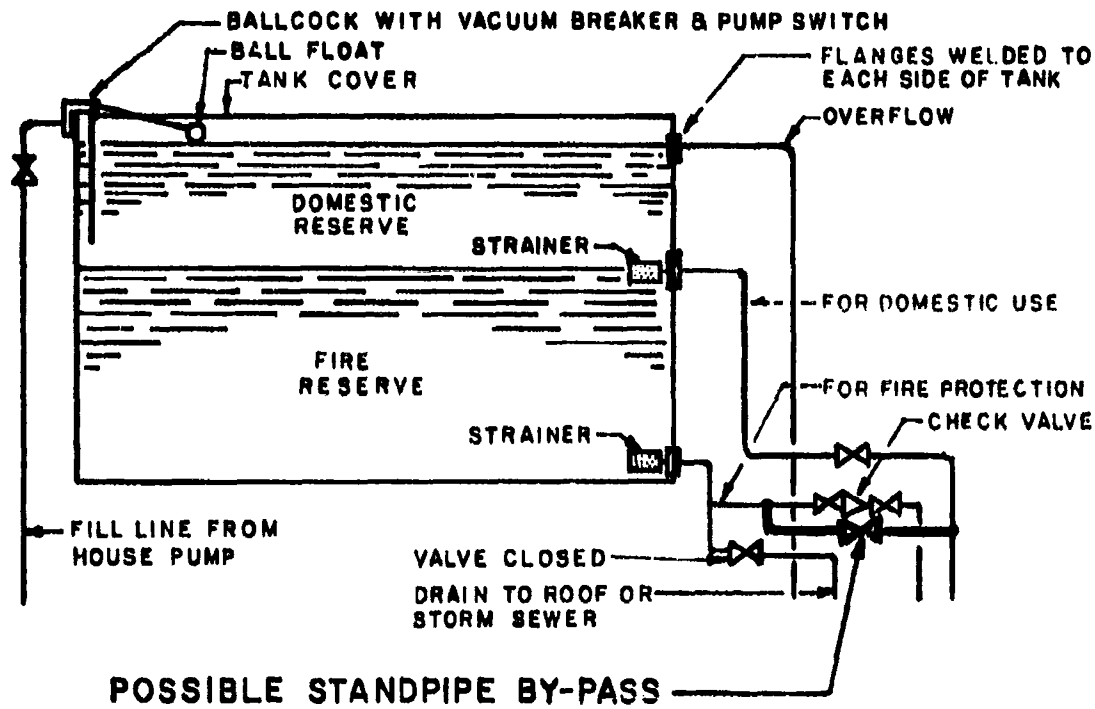
a. Quantity of fire reserve required by legislation or the National Board of Fire Underwriters. Generally 3500 gallons for buildings with one fire standpipe riser and 5,000 gallons for buildings with more than one, unless two tanks are used. In the latter event 3,500 gallons are generally reserved in each tank. A separate sprinkler reserve normally contains at least 5,000 gallons. (33)

b. Peak water use loads. Customary design procedure is to provide storage equivalent to one half hour's peak demand. The demand is, of course, a function of the occupancy usage of the building, the population and equipment (including air conditioning make-up requirements), and can range between 4 to 9 gallons per hour per person.

c. Economic relationship between pumps and house tanks. Often economic or architectural considerations limit the size of a tank in favor of larger or more continuously operated pumps. In some cases torque-drive pumps are used to wholly replace the domestic storage.

d. Industrial use. Water is often stored for industrial or commercial procedures such as in breweries and bottling plants. The amounts are quite variable and can range from a few thousand to hundreds of thousands of gallons.

Some consideration should be given to the use of the tank's fire reserve capacity. This water is usually available only through the fire standpipe system which may be non-potable due to stagnancy. It might be necessary to install a bypass such as is shown in Figure 6.11 in order to insure absolute potability of the water. The use of such a bypass however, is contrary to most local fire regulations.



TYPICAL HOUSE WATER TANK DETAILS
SHOWING POSSIBLE MODIFICATION TO BY-PASS STANDPIPE

FIGURE 6.11

Representative buildings in the New York City Area were surveyed in order to establish a spectrum of tank capacities normal to office buildings, light manufacturing and apartment houses. (34) These tanks are covered and normally on the roof or upper floors of the buildings. Non-Industrial Buildings as low as three stories high have been found to have tanks but they are more generally found on buildings over five stories high.

The results of this survey are given in tables 6.7, 6.8 and 6.9. Attention is directed to the fact that there are wide variations in water volume per square foot. This is to be expected and is consistent with common design interpretation of the parameters listed above. In order to establish an order of magnitude the duration of water supply to the building's population was estimated (Table 6.10). This is predicated on the assumptions that demand would be 1 quart per person per day, and that the fallout shelter population is the same as that of the building (estimated on an area basis).

6.1.3.2 Building Piping - Depending upon a multitude of factors, building plumbing systems may yield substantial quantities of potable water through gravity draining. As a rule this can be accomplished from outlets located within designated shelter locations (basements, core areas, etc.).

The amounts of water to be anticipated therefrom are subject to wide variation depending upon the number of plumbing, stacks, piping arrangement, type, size and height of building, etc. However, in order to establish an order of magnitude, domestic plumbing systems of typical buildings ranging from 10,000 to 30,000 sq. ft. per floor were studied. This data, based upon an assumed area of 100 sq. ft. per person, is shown in Figure 6.12, as a spectrum of maximum and minimum water availability.

Thus the hot and cold water domestic piping of a 20-story building could be expected to contain between 120 and 140 gallons. If the area of the building were to be known the water available per person could

TABLE 6.7

SURVEY OF LIGHT MANUFACTURING BUILDING WATER TANKS

	Total Tank Capacity (Gallons)	Gross Building Area (Sq. Ft.)	Gallons Per Sq. Ft.
1.	9,500	320,000	0.0296
2.	10,000	10,800	0.928
3.	20,000	72,800	0.275
4.	45,500	143,500	0.317
5.	10,000	22,400	0.446
6.	5,000	62,500	0.080
7.	5,000	26,400	0.189
8.	30,000	77,600	0.386
9.	38,000	171,000	0.222
10.	30,000	89,550	0.335
11.	37,000	324,000	0.114
12.	43,000	162,000	0.265

TABLE 6.8

SURVEY OF OFFICE BUILDING WATER TANKS

	Total Tank Capacity (Gallons)	Gross Building Area (Sq. Ft.)	Gallons Per Sq. Ft.
1.	35,000	472,000	0.074
2.	30,000	468,000	.064
3.	25,000	154,000	.162
4.	15,000	343,200	.044
5.	46,500	411,400	0.113
6.	14,000	182,200	0.077
7.	25,000	260,000	0.096
8.	12,000	140,000	0.085
9.	18,000	140,000	0.129
10.	14,000	140,000	0.100
11.	9,000	140,000	0.064
12.	24,000	323,000	0.074
13.	86,000	620,000	0.139
14.	17,500	128,700	0.136
15.	24,000	144,500	0.166

TABLE 6.9

SURVEY OF APARTMENT HOUSE WATER TANKS

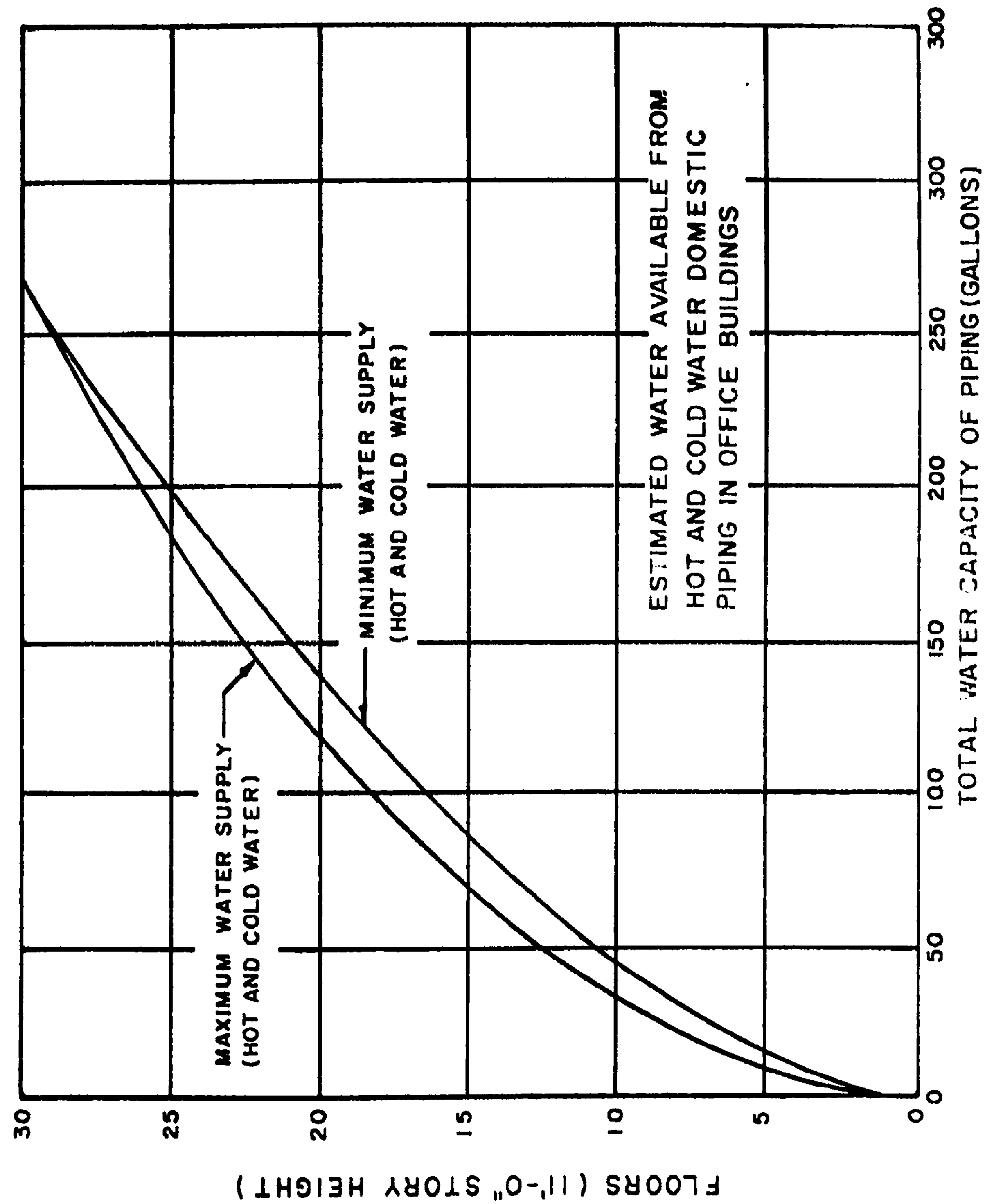
	Total Tank Capacity (Gallons)	Gross Building Area (Sq.Ft.)	Gallons Per Sq. Ft.
1.	58,800	25,000	0.425
2.	117,600	20,000	0.171
3.	2,106,000	73,000	0.0345
4.	194,000	54,000	0.278

TABLE 6.10

DURATION OF HOUSE TANK WATER SUPPLY

Type of Building	Average House Tank Capacity (Gal. per S.F.)	Estimated Peace-Time Area Per Person (Sq. Ft.)	Water Per Capita (Gallons)	Duration* of Supply (Days)
Office	0.102	100	10.2	40.8
Light Manufacturing	0.276	100	27.6	110.4
Apartment House	0.227	500	113.5	454.0

* Based on 1 Quart per person per day.



ESTIMATED WATER AVAILABLE FROM HOT AND COLD WATER DOMESTIC PIPING IN OFFICE BUILDINGS
MINIMUM WATER SUPPLY (HOT AND COLD WATER)
MAXIMUM WATER SUPPLY (HOT AND COLD WATER)
TOTAL WATER CAPACITY OF PIPING (GALLONS)
FLOORS (11'-0" STORY HEIGHT)
0
50
100
150
200
250
300
5
10
15
20
25
30

FIGURE 6.12

be estimated on an average basis of 100 sq. ft. of area per person.

Water from other piping arrangements such as heating, equipment connections, etc. are additive, but are too variable to estimate within significant limits.

6.1.3.3 Hot Water Storage Tanks - Hot water storage tanks are also subject to wide variations in capacity. In some of the more modern buildings they have even been supplanted by the instantaneous heating coil types which have no storage at all.

Where storage is provided, the capacity is mostly determined on the basis of the peak water demand. In general, capacities for apartment buildings are about 20 gallons per apartment. However, in some of the newer buildings which incorporate instantaneous heating coils this storage is reduced to about 8 gallons per apartment.

Assuming an average occupancy of 3.5 persons per apartment these storage figures work out to 5.7 and 2.3 gallons per person respectively.

Designers of office building hot water storage tanks base their requirements on population, heating period and duration of peak load. Generally, the usage is about 2 gallons of hot water per person per day. This works out to a total storage requirement of about 0.4 gallons per person.

6.2 SPRINGFIELD, MASS. STUDY

The ideal approach to the problem of water supply availability would be to evaluate in detail the water systems of each city and community with particular emphasis on its relationship to the fallout shelter program. By analyzing each shelter with respect to the amount of water available from the building itself, the outside distribution piping, and from various operational procedures of the supply plant itself, it would be possible to make good quantative estimates of water availability.

Such an extensive undertaking is of course beyond the scope of this report, but in order to demonstrate the value of such a survey, and to test some of the generalizations made herein, it was decided to evaluate one arbitrarily selected city. Springfield, Massachusetts was chosen for this introspection after having met the following pre-set criteria:

a. Population between 100,000 and 500,000. (This criterion established on the basis that the mean population of the 676 U. S. cities of over 25,000 population is 265,000.)

b. Has own water supply and treatment plant.

c. Federal program of locating and marking fallout shelters well under way.

d. Contains varied industrial, commercial and residential buildings.

e. Has urban and sub-urban areas.

Specifically, the city was studied to determine the type of water supply system, the method of distribution and the relationship of marked fallout shelters to the water system in order to estimate the amount of uncontaminated water expected to be available in an emergency, and to evaluate the system vulnerability.

6.2.1 General Description -

The city of Springfield, Mass. is located in the southwestern part of the state on the eastern bank of the Connecticut River. It is about five miles north of the Connecticut state line in Hampden County; has a daytime population of about 250,000, and a nighttime population of approximately 178,000.

The city covers about 40 square miles resulting in an average night-time population density of 4450 persons per square mile. It is the industrial center of Western Massachusetts and draws employees from the neighboring communities of West Springfield, Agawam, Long Meadow, East Long Meadow, Chicopee, Wilbraham and Ludlow.

Westover Air Force Base is located about 5 miles north of the center of Springfield in the city of Chicopee.

Elevations range from about 57 feet above mean sea level in the business section of the city to a maximum of about 337 feet in the residential areas.

Mean annual precipitation is approximately 44" occurring on the average of 1 day out of 3. Snow accumulation is about 55 to 75 inches annually, occurring over 20 days or more having snowfalls of 1" or greater. The prevailing wind on a yearly basis is from a westerly direction. It is more northwesterly in winter and southwesterly in summer. (35)

6.2.2 Civil Defense Posture - At the present time some 75,000 spaces have been located in the OCD "4" to "8" category, that is, with a protection factor of 100 or better. These spaces are mostly concentrated in the one square mile downtown business district.

An additional 75,000 spaces are available in the "2" and "3" categories (protection factor: 40 to 100), but many of these spaces are located in lesser protected areas of the same buildings in the "4" to "8" category.

At the time of writing some 43% of the 100 or more protection factor shelters have been marked and stocked with food, first aid and sanitary supplies, and 17 1/2 gal. drums of water in the amount of one quart per person per day. The program, under management by a city director, closely follows the federally sponsored marking and stocking fallout shelter plan. (26)

6.2.3 Description of Water Supply System

Springfield has a surface water supply with a dependable yield of approximately 65 million gallons per day. (37) The adjacent Ludlow system presently supplies about 800 million gallons per year to the Town of Ludlow and industry. The Ludlow system no longer supplies water to Springfield, but existing pipe connections could provide an estimated 2 million gallons per day in an emergency. The Ludlow system originates about 10 miles east of Springfield. Treatment facilities consist of an aerator, four acres of open slow sand filters and chlorinators.

The Springfield system or "Little River System" presently supplies about 13,000 million gallons per year to Springfield and adjoining communities. Cobbler Mountain reservoir on the Little River is approximately 20 miles east of Springfield (Figure 6.13). The water shed consists of 48.5 square miles of sparsely settled mountainous woodland, 38.8 percent of which is owned by the City of Springfield. The reservoir has a capacity of 22.5 billion gallons. Water withdrawn from the reservoir flows about 8,000 feet through a 10' diameter tunnel to a power house which is operated by a private company under lease with the City of Springfield. The water then flows into an intake reservoir having a capacity of 40 million gallons. A mile-long tunnel diverts water to the open sedimentation basin at the West Parish Filters which has a capacity of 43 million gallons (Figure 6.14).

Water flows from the sedimentation basin to 14 covered slow sand filters having a total area of about 7 acres and a maximum capacity of 50 mgd. Each filter (which is valved to permit periodic cleaning of the sand) contains 38 inches of sand and 12 inches of gravel. Filtered water flows through 3 pipes to the Provin Mountain Reservoir about 7 miles closer to the City.

A control building at the West Parish Filters contains control valves, a small turbine generator for auxiliary power, and a laboratory. Daily chemical

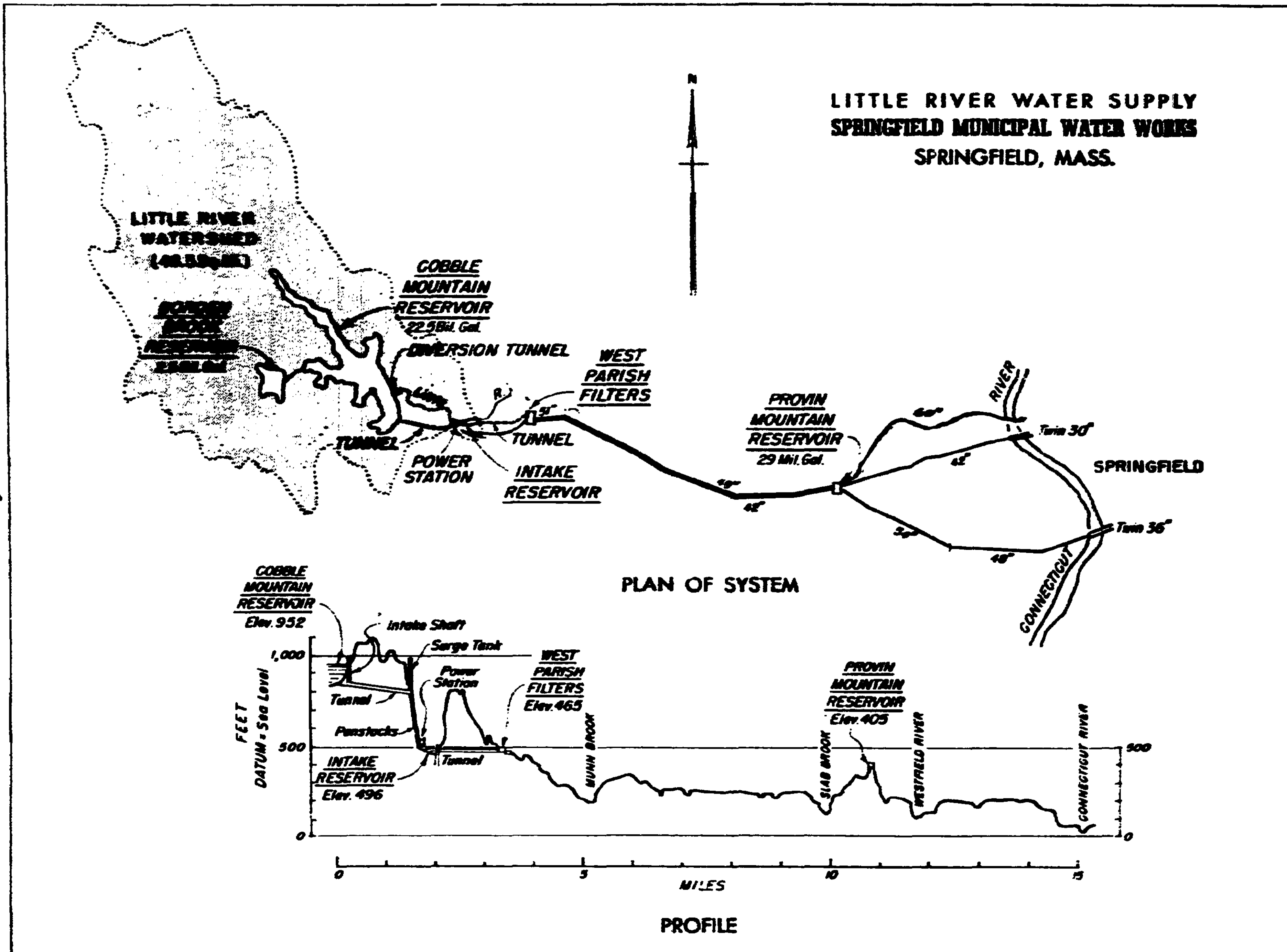
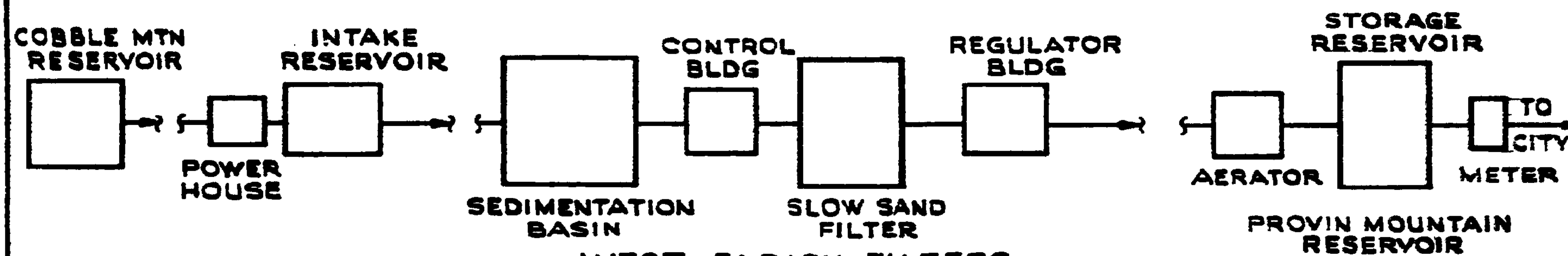
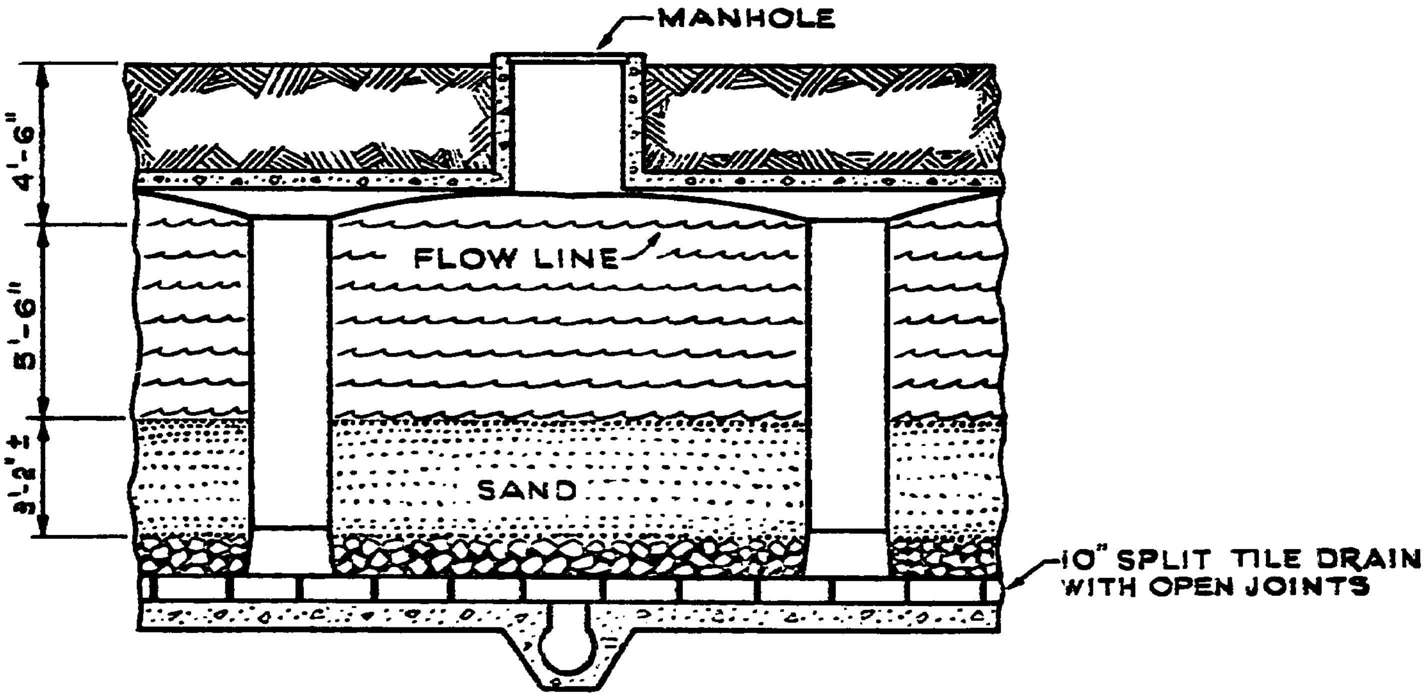

LITTLE RIVER WATER SUPPLY
SPRINGFIELD MUNICIPAL WATER WORKS
SPRINGFIELD, MASS.
N
LITTLE RIVER WATERSHED
COBBLE MOUNTAIN RESERVOIR 22.5 Bil. Gal.
DIVERSION TUNNEL
WEST PARISH FILTERS
TUNNEL
POWER STATION
INTAKE RESERVOIR
PROVIN MOUNTAIN RESERVOIR 29 Mil. Gal.
RIVER
Twin 30"
SPRINGFIELD
Twin 36"
CONNECTICUT
PLAN OF SYSTEM
COBBLE MOUNTAIN RESERVOIR Elev. 952
Intake Shaft
Surge Tank
Power Station
Tunnel
Penstocks
WEST PARISH FILTERS Elev. 465
INTAKE RESERVOIR Elev. 496
MUNN BROOK
SLAB BROOK
PROVIN MOUNTAIN RESERVOIR Elev. 405
WESTFIELD RIVER
CONNECTICUT RIVER
FEET
DATUM = Sea Level
1,000
500
0
5
10
15
MILES
PROFILE

FIGURE 6.13



WEST PARISH FILTERS
FLOW DIAGRAM



SECTION THROUGH SLOW SAND FILTER
SPRINGFIELD, MASS.

FIG. 6.14

and bacteriological examinations of raw, settled and filtered water are conducted. Frequent analysis of tap water from various points in the distribution system are also made.

Provin Mountain Reservoir consists of two rectangular reinforced concrete tanks and two circular prestressed concrete tanks. All tanks are covered and provide a total storage of 60 million gallons. Water is normally aerated before being stored in the reservoir, but the aerators may be by-passed if desired. Portable chlorination equipment is available for emergency use only, but dependence for chlorine supplies is placed upon stock of local distributors rather than by stockpiling.

Water from Provin Mountain Reservoir is metered and flows through 3 large pipes to the distribution system (Figure 6.14). Table 6.11 lists the diameter and length of pipes in the distribution system.

The entire water supply system, from Cobble Mountain Reservoir to building outlets, acts under gravity and requires no pumping. Power required at West Parish Filters for maintenance can be supplied by the turbine generator operated under the head from the sedimentation tank.

The city has a number of privately owned wells which are used for cooling and other commercial uses, but no official records are kept of their number, capacity or location. The neighboring community of West Springfield incorporates wells in the supply system.

6.2.4 Vulnerability of Water System to Fallout Contamination

Many components of the Springfield water supply system are naturally resistant to fallout contamination and even, to a very limited degree, to certain direct weapons effects. However, because it is a surface supply the system has certain inherent

TABLE 6.11

SUMMARY OF SUPPLY AND DISTRIBUTION

MAIN PIPE IN USE JANUARY 1, 1961

SPRINGFIELD, MASS. WATER SYSTEM (38)

Size (Inches)	Length (Feet)	Volume, Gallons (000) omitted
3/4	313	0
1	8,792	0
1-1/4	17,507	1
1-1/2	15,592	2
2	52,628	9
2-1/2	165	0
4	45,385	30
6	515,728	774
8	1,410,125	3,662
10	96,733	396
12	131,892	767
16	133,703	1,269
18	12,922	157
20	20,231	306
24	89,284	1,971
24-1/2	32	1
30	53,464	1,866
36	75,629	3,834
42	64,276	4,460
48	50,656	4,762
51	8,671	919
54	16,168	1,915
60	26,739	519
66	279	3,917
72	23	50
		5
	TOTAL	31,592

points of vulnerability which could bring about cessation of operations in this type of emergency. In keeping with the scope of this report these points are discussed here without speculation as to the degree of fallout contamination likely or to the possibility of direct weapons effects on the system or the demand.

6.2.4.1 Uncovered Components - The West Parish sedimentation basin, the intake reservoir, the Cobble Mountain Reservoir, the Bordon Brook Reservoir and of course the 48.5 square mile Little River Watershed are all open and subject to direct fallout contamination. Water is similarly exposed to the atmosphere at the aerators at Provin Mountain Reservoir and at the West Parish Filter Plant. The latter, a single unit, is no longer a part of the treatment but is kept operating for aesthetic reasons. Both aerators and the sedimentation basin can be bypassed if necessary.

6.2.4.2 Shut off valves and bypasses

While the system is so designed that nearly all components can be shut off or bypassed, some of these valves are not located advantageously from a Civil Defense point of view. These include:

a. Main shut-off gate at Cobble Mountain Reservoir - This is a 55 ton electrically operated gate which controls water going to the power plant. It is operated from the intake building but the attenuation factor for personnel is too low for adequate protection against fallout.

b. Provin Mountain Aerator bypass: This is operated from a masonry building with a concrete roof. The protection factor could be adequate if provisions are made to block the door and windows.

c. West Parish Sedimentation basin bypass: This gate controls flow into the filters. It is hydraulically operated from within a masonry control building with a high protection factor in the lower levels. Its use as a personnel shelter is compromised by water which condenses on the supply pipes and is not adequately drained off.

d. West Parish Aerator and Filter Gates: The aerator and some of the filters can be controlled from the Laboratory building - a 2 story plus basement masonry structure. Potential as a personnel fallout shelter is good. Only relatively minor modifications such as blocking windows and providing ventilation and sanitary provisions appear necessary. The laboratory is on the top floor and probably could not be used except under certain conditions of fallout.

6.2.4.3 Sampling - The obtaining and checking of samples during a fallout emergency could present a serious problem. These are obtained manually from points all along the system, and brought to the laboratory for analysis. Since the laboratory itself is relatively unprotected, both phases of this operation are vulnerable to fallout radiation.

6.2.5 Factors Favoring Survivability of the System

Acting in favor of the continuity of at least emergency supplies are the following factors:

a. Except for the intake reservoir and the sedimentation basin, both of which can be bypassed, the entire system is closed from the main intakes at Cobbler Mountain to consumer.

b. The entire system is gravity flow with no necessity for pumping or elevated storage tanks in the city.

c. Large volumes of water are stored in covered reservoirs and can be easily controlled.

d. Alternate sources of water are available through the Ludlow supply, and the nearby Boston supply. If necessary the Connecticut River could also be used as a source if radiation levels permitted. Since it is a relatively fast-moving river it is possible that an upstream slug of radioactive contamination might be avoided through judicious withdrawal.

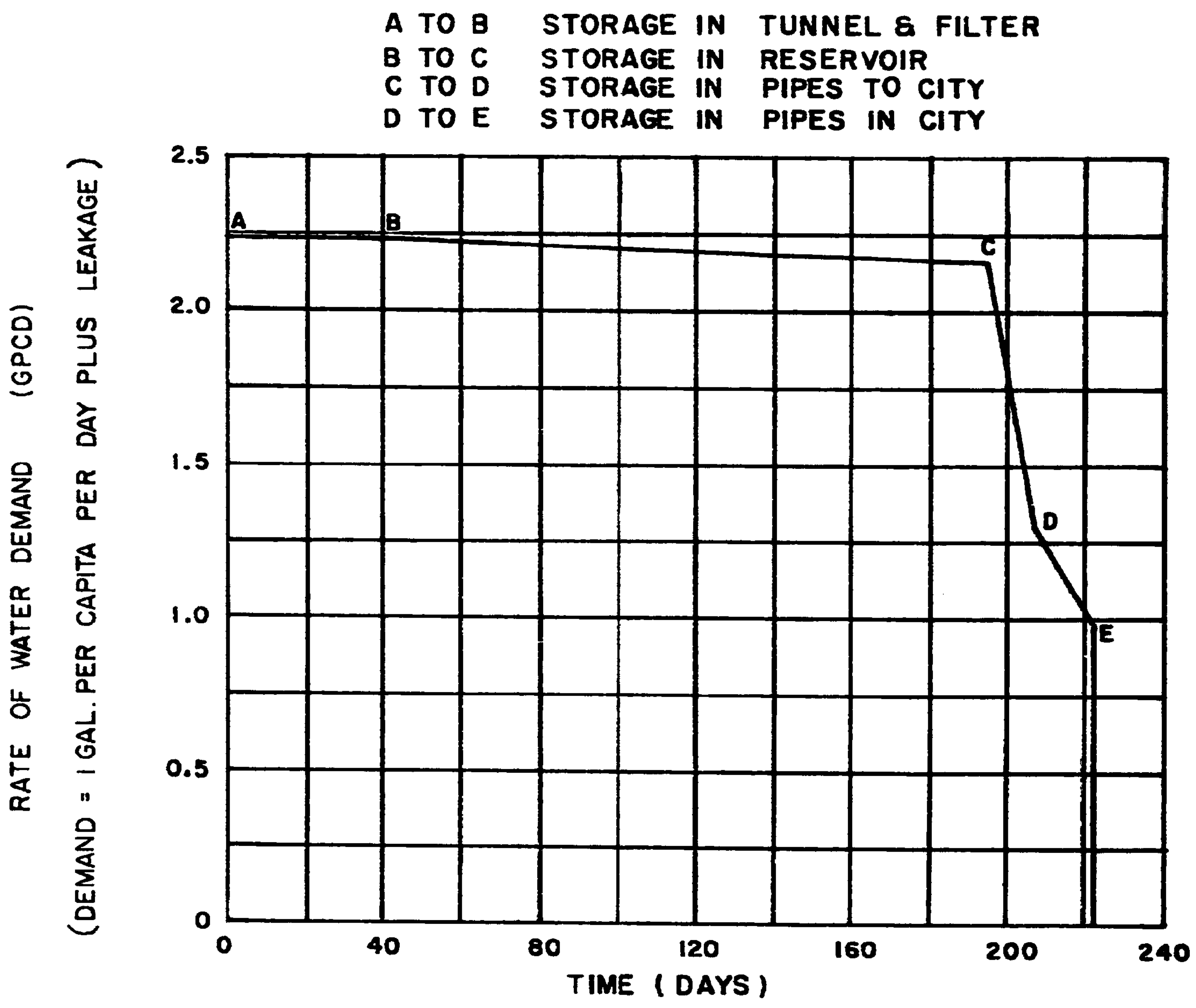
6.2.6 Relationship of Demand to Supply

Geographically, Springfield follows closely the generalizations made in section 6.1.2.1.1 insofar as the distribution of fallout shelter spaces is concerned. These are situated mostly near the Connecticut River and so located physically as to enhance the prospect of gravity drainage of the water system during the shelter phase. Some of the shelters located in the higher sections might lose the piping system as a gravity source, but all parts of the city would have available the water in the surge tank, distribution reservoir, and filters. These sources alone comprise a total of 76,577,000 gallons or 429.2 gallons per capita (not including leakage). Of course the dependency of this supply is a function of the post-attack situation. Direct blast damage to the water distribution system or use of water for fire fighting could very well reduce substantially or even completely negate the supply.

6.2.7 Availability of Uncontaminated Potable Water

Without fresh water supplies, Springfield has sufficient quantities of covered public water storage which, if properly conserved, could last for nearly 16 months. This is based on minimum demand of one gallon per capita per day with no loss of water due to leakage, fire fighting, decontamination, etc., and only 30% recovery of the water in the distribution piping. If this were all to be distributed via the distribution system with its current leakage rate of 81,300,000 gallons per year (this includes 2,000,000 gallons fire loss and 5,000,000 gallons breakage loss), the supply could last about 7-1/2 months. Figure 6.15 shows the estimated demand - duration relationship including leakage and 30% recovery of distribution piping supplies.

Additional quantities of water are obtainable from the plumbing of buildings to be used as fallout shelters. These have been estimated according to a



WATER STORAGE SPRINGFIELD, MASS.
FIGURE 6.15

Corps of Engineers sampling procedure. A summary of these sources and the resulting per capita quantities is given in Table 6.12.

TABLE 6.12

EMERGENCY WATER AVAILABILITY - SPRINGFIELD, MASS.

	Source	Gross Quantity (Gallons)	Gallons per Capita (Without Leakage)
I.	Covered Storage		
	a) Surge Tank	577,000	3.2
	b) Distribution Reservoir	60,000,000	336.0
	c) Filters	16,000,000	90.0
II.	Supply and Distribution Piping	31,600,000	178.0
III.	Interior Building Plumbing (+)		
	a) Shelters with P.F. > 100 -	927,000	12.3 *
	b) Shelters with P.F. < 100 -	737,000	13.8 **

NOTE: Except where indicated otherwise, gross quantity per capita is based on 178,000 population.

* 75,168 shelter spaces surveyed
** 53,548 shelter spaces surveyed

(+) Based upon summary of data reported by the U. S. Army Corps of Engineers sampling of 1000 buildings.

SECTION 7

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The problems raised by the potentialities of a fallout-contaminated water system are many and varied. Compared with some of the direct effects of nuclear detonations such as blast overpressure and thermal effects, a fallout-contaminated water supply becomes a secondary concern. However, once the exigencies of post-attack survival are surmounted, a potable water supply assumes immediate and paramount importance.

While the extent and degree of contamination to be anticipated remains a matter of hypothesis, sufficient spectra of significant factors can be established to permit certain generalities and specifics to be drawn regarding system vulnerability and protection.

This report confines itself to the study of fallout-contaminated water systems to the exclusion of direct blast effects upon the system or the demand. No attempt is made to rationalize the extent or degree of fallout contamination; but only to investigate the ramifications of the degrees of intensity once introduced into the system.

7.1 WATER SYSTEM CIVIL DEFENSE PROBLEMS COMPARED TO THOSE OF OTHER UTILITIES

While the maintenance and repair problems of most vital utilities have much in common, water supply systems are unique in one respect - the quality of the product is immediately compromised in a fallout environment.

A consensus of preferred methods of protecting vital facilities reveals that the trend is toward development of procedural methods of damage assessment, control and repair in the post-attack period, and the protection of operating and maintenance personnel.

Most of the techniques developed in this light are applicable to water supply systems. However, water system operators must be also aware of the vulnerability of their product to direct contamination and it is incumbent upon them to find means of minimizing this hazard.

A summary of recommendations pertaining to vital utilities in general encompasses the following basic needs.

a. Personnel Shelters for key personnel.

b. A system of damage assessment.

c. A radiological survey of the area.

d. A stock-piling program of vital material.

e. A mutual aid agreement with nearby utilities.

f. Anticipation of the type and degree of damage and development of techniques required for repair.

7.2 VULNERABILITY OF WATER SYSTEMS

The individual nature of water supply systems is such as to preclude analysis by category. It would not be possible, for instance, nor is it the intent of this report, to determine for a specific type of plant, under a certain fallout environment, that valve "X" should be closed or that bypass "Y" should be opened. This type of detail planning is necessary and vital, but can only be of significant value on an individual system study basis. A general description of system components and the effect of fallout upon them and water quality was presented in sections 4 and 5. Following is a summary of conclusions derived therefrom.

7.2.1 Ground Water Supplies

Ground water resources may generally be considered free of contamination due to the relatively slow passage of water through the soil. Since this process may take weeks or even centuries, decay and filtration may generally be relied upon to effectively reduce contamination to within potable limits.

The only source of direct contamination of ground water supplies is through deposition of fallout into open reservoirs and tanks in the treatment plant and distribution system. However, because of probable great dilution this contamination does not represent too serious a hazard. In any event, installation of protective covers and/or proper bypass equipment would serve to protect against even this marginal degree of contamination. Nearly half of the U.S. population is presently served, wholly or in part, by ground water resources. Potential quantities are available throughout the United States to supply the emergency requirements of the entire population, although in many areas distribution would be economically unrealistic.

7.2.2 Surface Water Supplies

Contamination of surface supplies comes about through two general sources:

A. Deposition of fallout directly on reservoir and tanks.

B. Contribution of runoff from contaminated drainage basins.

A study of the effects of various parameters on degree of contamination from both these sources is summarized below. The base assumptions and conditions given in section 5 should be noted.

a. Contamination after sedimentation in reservoirs of various depths -

(1) For given surface concentrations, contamination varies inversely as the depth of the reservoir.

(2) At surface concentrations of 3,000 r/hr. at 1 hour, the time required for water to reach

10 day wartime potability standards is on the order of from 2 to 5 days as depth varies from 60 ft. to 10 ft. respectively.

(3) At surface concentrations of 3,000 r/hour at 1 hour, the time required for water to reach 30 day wartime potability standards is on the order of from 4 to 8 days as depth varies from 60 ft. to 10 ft. respectively.

(4) Holding other conditions constant, fallout containing large particle soils with result in lower water contamination levels than fallout containing small particle soils. This is due to more rapid sedimentation of the heavier particles, but the overall effect is not as significant as that due to other variables.

b. Effect of treatment in Reducing Contamination (No Contributory Runoff) -

(1) Lime soda-ash softening plus sand filtration is about 30% more efficient in reducing contamination than alum coagulation plus sand filtration.

(2) Ion-exchange or distillation (99% removal) is about 35 times more efficient in reducing contamination than alum coagulation plus sand filtration.

(3) At surface concentrations of 3,000 r/hour at 1 hour the comparative time required for water to reach various standards of potability after treatment is in the following table:

Treatment	Comparative Time Required for Water to Reach Indicated Potability Standard (Days)		
	10-day Wartime	30-day Wartime	Peacetime
Lime soda-ash softening and sand filtration	0.8	2.8	---
Alum Coagulation and sand filtration	1.3	3.5	---
Distillation or Ion Exchange 99% Removal	0	0	15.5
Distillation or Ion Exchange 99.9% Removal	0	0	4.7

c. Fallout on land and water areas -

(1) The ratio of watershed to reservoir area has a pronounced effect upon the significance of depth of runoff in contributing contamination.

(2) An increase in the content of insoluble fallout in runoff from 1% to 5% increases contamination by a factor of about 3.

(3) An increase in the content of soluble fallout in runoff from 1% to 10% increases contamination by a factor of about 1.5.

(4) An increase in solubility of fallout from 10% to 50% increases contamination by a factor of about 1.8.

d. The Effect of treatment on reducing contamination (Including Runoff) -

At surface concentrations of 3,000 r/hr. at 1 hour, 3" depth of runoff, and a ratio of watershed to reservoir area of 100, the time required for water to reach various standards of potability after treatment is as follows:

Treatment	Comparative Time Required for Water to Reach Indicated Potability Standard (days) 10-day Wartime	30-day Wartime	Peacetime
No Treatment except sedimentation in Reservoir	12.5	--	--
Lime Soda-ash Softening and sand filtration	6	10	--
Alum Coagulation and sand filtration	7	12.8	--
Ion Exchange or Distillation 99.9% Removal	0	0	10.3

7.3 PROCEDURES FOR REDUCING THE VULNERABILITY OF WATER SYSTEMS

It is to be stressed that each water supply system requires individual study to determine its particular points of vulnerability and protection requirements.

This study should not be confined to the limits of the particular system, but should be extended to encompass all pertinent geographical and physical factors of the surrounding terrain. Neighboring water systems and possible interconnections are definite factors to consider.

As a general guide to the possible conduct of such an investigation, the following outline is suggested.

a. Determine the vulnerability of the system.

(1) Study topographic maps of the general area and plans of the water system including those of neighboring systems.

(2) Conduct a field inspection of the system.

(3) Consult with plant personnel to determine management, planning, operating and maintenance policies of the system.

(4) Determine those units of the system which are vulnerable to the entry of fallout, either directly or indirectly.

(5) Compute the probable extent of water contamination due to a nuclear attack based upon spectra of fallout patterns.

(6) Determine the ability of the system to meet minimum and normal demands for water for various uses following a nuclear attack, both quantitively and qualatatively.

b. Develop alternate schemes for supplying minimum and normal demands for water during the shelter and post-shelter phase. - Alternate schemes capable of functioning after a nuclear attack should consider incorporation of some of the following methods of reducing vulnerability.

(1) Protection of operating and maintenance personnel.

(2) Protection of reservoirs or other exposed bodies of water from fallout.

(3) Automatic or remote operation of the water system from a protected area.

(4) Continuous radiological monitoring.

(5) Contamination forecasting system.

(6) Emergency power supply.

(7) Inventory of spare parts and expendable supplies.

(8) Reserve pool of well-trained personnel at all levels.

(9) Treatment of contaminated water.

(a) Conventional treatment.

(b) Special treatment (ion exchange or distillation).

1. Stationary units (various capacities, from minimum to normal requirements).

2. Portable or mobile units (small to medium capacity).

3. Small capacity units for shelter or early post-shelter use.

(10) Color coding of water to indicate the degree of contamination.

(11) Hauling potable water.

(12) House-to-house distribution of potable water.

(13) The use of alternate sources of water including:

(a) Uncontaminated surface water supplies.

(b) Ground water.

(c) Stored water.

1. Impounding reservoirs.

2. Distribution reservoirs.

3. Distribution piping.

4. House tanks and building plumbing.

5. Tanks and containers of various sizes.

(14) Modifications in operating procedures such as:

(a) By-passing contaminated sections.

(b) Wasting contaminated water.

(c) Selective withdrawal of the least contaminated water available in the system.

(d) Other procedures utilizing dilution, sedimentation and radioactive decay to reduce contamination.

c. Evaluate the various schemes for each system and present definite recommendations for further action. - The results of each study should be summarized in a written report containing the following information.

(1) A complete description, including schematic plans showing operation of the system after a nuclear attack.

(2) Detailed recommendations regarding.

(a) Stocking of supplies.

(b) Modifications of existing equipment.

(c) New equipment.

7.4 ALTERNATE SOURCES OF WATER

Many significant sources of potable water are available in the event of system shutdown, and need only development of extraction methods. Some of these sources are easily obtainable; others may require extensive construction and expenditure. While the complexities of some sources defy accurate estimation of the quantities to be derived therefrom, indications are that all are significant and may go a long way toward solving the shelter phase water supply problem.

7.4.1 Well Water

The immediate and long range benefits of well water are covered in a concurrent report by Guy B. Panero Inc. (28) Ground Water Resources are widely available, and in most large cities are already utilized for private or municipal water needs. Capacities for individual wells vary, but can be from 1 or 2 gallons per minute to over 3,000 gpm.

7.4.2 Distribution System of Water Supply Utility

Considerable quantities of water are contained in covered storage tanks and piping systems of the water system. Statistics from an investigation of 25 cities shows that 100% of the population studied has a 17-day minimum supply; 71% has a 30-day minimum supply, and 48% has a 60-day minimum supply. These figures are based upon demand at 1 quart per person per day, leakage at 5% of average peacetime demand and 30% recovery of water trapped in mains. At a demand of 1 gallon per person per day 67% of the population has a 14 day minimum supply. If leakage of stored water, the major cause of depletion, could be eliminated, perhaps through such methods as local distribution, the minimum duration of supply would be considerably extended. In this event, a statistical 100% of the population would have over 14 days supply at 1 gpcd.

7.4.3 Building Plumbing

While there are many sources of trapped potable water within buildings, three sources seem to be most commonly available and of more noteworthy interest.

7.4.3.1 House Gravity Tanks - A spot survey of house tanks for office buildings, light manufacturing plants and apartment houses indicates average capacities of 10.2, 27.6 and 113.5 gallons per occupant, respectively. These are based on average occupancies of 100 sq. ft. per person for offices and manufacturing plants, and 500 sq. ft. per person for apartment houses.

7.4.3.2 Piping - Largely a function of type and size of building, water trapped in building piping is difficult to estimate in general terms. An analysis of office building design practices indicates that the source is significant in terms of emergency demand.

A spectrum of anticipated quantities from this type of building is given in Figure 6.12.

7.4.3.3 Hot Water Storage Tanks

Depending on type of equipment, this source could be expected to yield between 2.3 and 5.7 gallons per person for apartment buildings and about 0.4 gallons per person for office buildings.

7.4.4 Springfield, Massachusetts Study

A spot check of water availability from the above sources was made for Springfield, Mass. This study shows a potential supply of potable water at 1 gpcd of about 7-1/2 months at present leakage rates and assuming only 30% recovery of the trapped water in the mains. An additional 12.3 to 13.8 gpcd is available through draining of building plumbing.

7.5 RECOMMENDATIONS FOR CONTINUED RESEARCH

During preparation of this report, certain areas of technical nebulousness were uncovered. It is felt that further research on the following subjects would be of significant value:

a. Determination of the short and long term affects on the body due to the ingestion of contaminated water, and relationship of this dose to varying degrees of external dose.

b. A detailed study of the relative proportions of soluble and insoluble fallout likely to enter the drainage basin, and the amounts expected to be carried into the water system by runoff.

c. A continuation of the study of treatment methods in the expectation of obtaining improvements in both performance and cost.

d. A further study along the lines covered in Section 7 to determine and develop alternate sources of water - particularly trapped water in water systems and buildings.

e. A detailed investigation into the possibilities and costs of decontaminating only minimum drinking water requirements, while continuing to operate the water system for other uses. Distribution of the potable water along the lines given in section 6 is suggested.

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APPENDIX A

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APPENDIX B

BULK HAULING OF

WATER VIA GASOLINE

TRUCKS

T E X A C O
INC.
PETROLEUM PRODUCTS

RESEARCH & TECHNICAL DEPARTMENT
TECHNICAL SERVICES
W. A. McMILLAN, MANAGER

P. O. BOX 509
BEACON, NEW YORK

September 16, 1963

Mr. Peter W. Welch
Guy B. Panero, Inc.
468 Park Avenue South
New York 16, N. Y.

Dear Sir:

Your inquiry of July 23 concerning the transporting of safe drinking water by truck or train during nuclear attack and the feasibility of using gasoline trucks for this service was referred to us for handling.

Our Shipping Division has commented as follows in connection with tank truck rates for water:

"The assumption of Guy B. Panero, Inc. that the cost of shipping Gasoline by tank truck would approximate the cost of hauling water via tank truck could be correct on a tank truck load basis. However, please note in the rates listed below for your information that the water rate to a destination is higher than the Gasoline rate. This difference develops because water weighs approximately 8.3 pounds per gallon, whereas the transportation weight of Gasoline is generally accepted to be 6.6 pounds per gallon.

We have listed below tank truck rates from Bayonne, New Jersey for both water and Gasoline on the mileage and specific rate basis. Please also note that there is no universal rate scale but that the tank truck rates for water would vary from one section of the United States to another.

Best Available Copy

MILEAGE RATES FROM BAYONNE, N. J.
(in dollars per gallon)

Mileage	To New York State Points		To Points in Delaware, Maryland, Pennsylvania and Virginia	
	Water	Gasoline	Water	Gasoline
15	$0.00690	$0.00510	$0.00530	$0.00380
25	.00810	.00590	.00700	.00490
50	.01190	.00870	.01160	.00830
75	.01650	.01200	.01600	.01140
100	.02150	.01560	.02140	.01520
150	.02980	.02170	.03140	.02240
200	.04090	.02980	.04270	.03060
250	.05150	.03750	.05480	.03900
300	.06300	.04600	.07280	.05170
350	.07510	.05480	.08630	.06150
400	.08770	.06400	.09690	.06890
450	.10110	.07360	.10900	.07760
500	.11600	.08400	.12140	.08630

Specific Rates from Bayonne, N. J.
(In dollars per gallon)

Destination	Water	Gasoline
Albany, New York	$0.02980	$0.02170
Baltimore, Maryland	.04110	.02630
Beacon, New York	.01650	.01200
Kingston, New York	.02150	.01560
Philadelphia, Pennsylvania	.01950	.01370

Minimum gallons applicable for shipment under the above mileage and specific rates are: Water-4,200 gallons; Gasoline-5,800 gallons."

In regard to whether it would be feasible or not to use gasoline trucks for the shipment of water, our Health Division has offered the following comments:

"Emergency transportation of potable water by gasoline trucks is not new. During the St. Patrick's flood in Harrisburg in 1936, the city water supply system was unable to operate because the flood waters crested one foot above the top of the dikes. An oil company supplied a fleet of gasoline trucks to transport water from nearby wells to a high point in the city where a relief reservoir was located. The gasoline trucks had been in service in Philadelphia. They were dispatched from Philadelphia and filled with water and a detergent. They traveled to Lancaster, a distance of about 65 miles, where the detergent solution was drained and the tanks refilled with potable water. When the trucks arrived at Harrisburg, the tanks were drained again to remove traces of the detergent and the trucks were put into service immediately hauling water to supply the city. This operation continued for at least three days to the best of my recollection. There was no taste of gasoline in the water during this emergency period. The Panero Company could probably get more details by writing to the City Health Department of Harrisburg, Pennsylvania.

Any traces of gasoline that might be picked up by water being transported in tank trucks because of an emergency, such as a nuclear attack, might have a gasoline taste but I am quite sure that no public health problem would result."

It is hoped that this information will be satisfactory for your purposes and that you will advise if we can be of further assistance.

Very truly yours,

W. A. McMillan

W. A. McMILLAN

DLD-LLT

APPENDIX C

This appendix is a background review of the water cycle, the demand and uses for water and the treatment and distribution systems commonly employed. Since no two systems are exactly the same, no discussion of them can evolve around a "typical" system. The basic components described here are those commonly in present use in various combinations throughout the United States.

APPENDIX C

WATER SUPPLY SYSTEMS

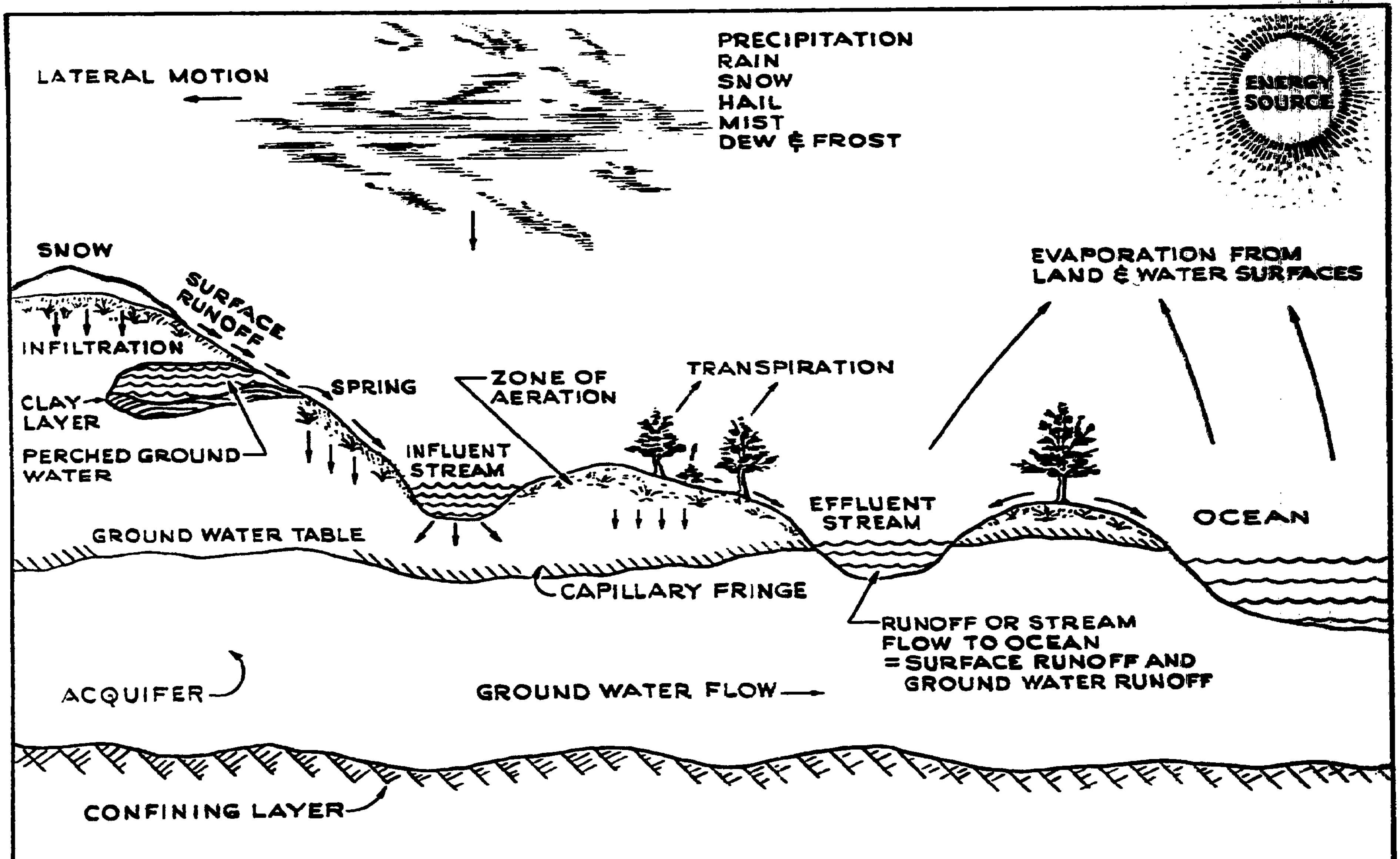
C.1 THE WATER CYCLE

The origin of water on earth remains a matter of supposition. It is known, however, that the amount of water is essentially constant and that a portion of the water is in continual change from the liquid to vapor state and then back to liquid form. (9) This constant activity constitutes the hydrologic or water cycle, and is schematically presented in Figure C.1.

Surface water in liquid form is present in lakes, streams, swamps and the oceans; the latter comprising, by far, the greatest quantity.

With the sun as the source of energy, water evaporates from these surfaces and from the land to form water vapor. It remains in this state, moved by wind and other forces, until converted to precipitation in the form of rain, snow, hail, etc. Some of this precipitation flows over the earth's surface to streams and thus eventually to the ocean. The remainder infiltrates into the soil where a large portion constitutes the ground water supply. Other infiltrated water is evaporated from the soil, adheres to the soil particles as hygroscopic moisture or is consumed by vegetation and transferred to the atmosphere by transpiration.

Ground water moves laterally very slowly and



THE WATER CYCLE

FIG. C.1

may appear as springs where it intersects the ground surface. As shown in figure C.1, it may be fed from an influent stream or flow into an effluent stream. Many rivers maintain a constant base flow throughout the year which originates from ground water.

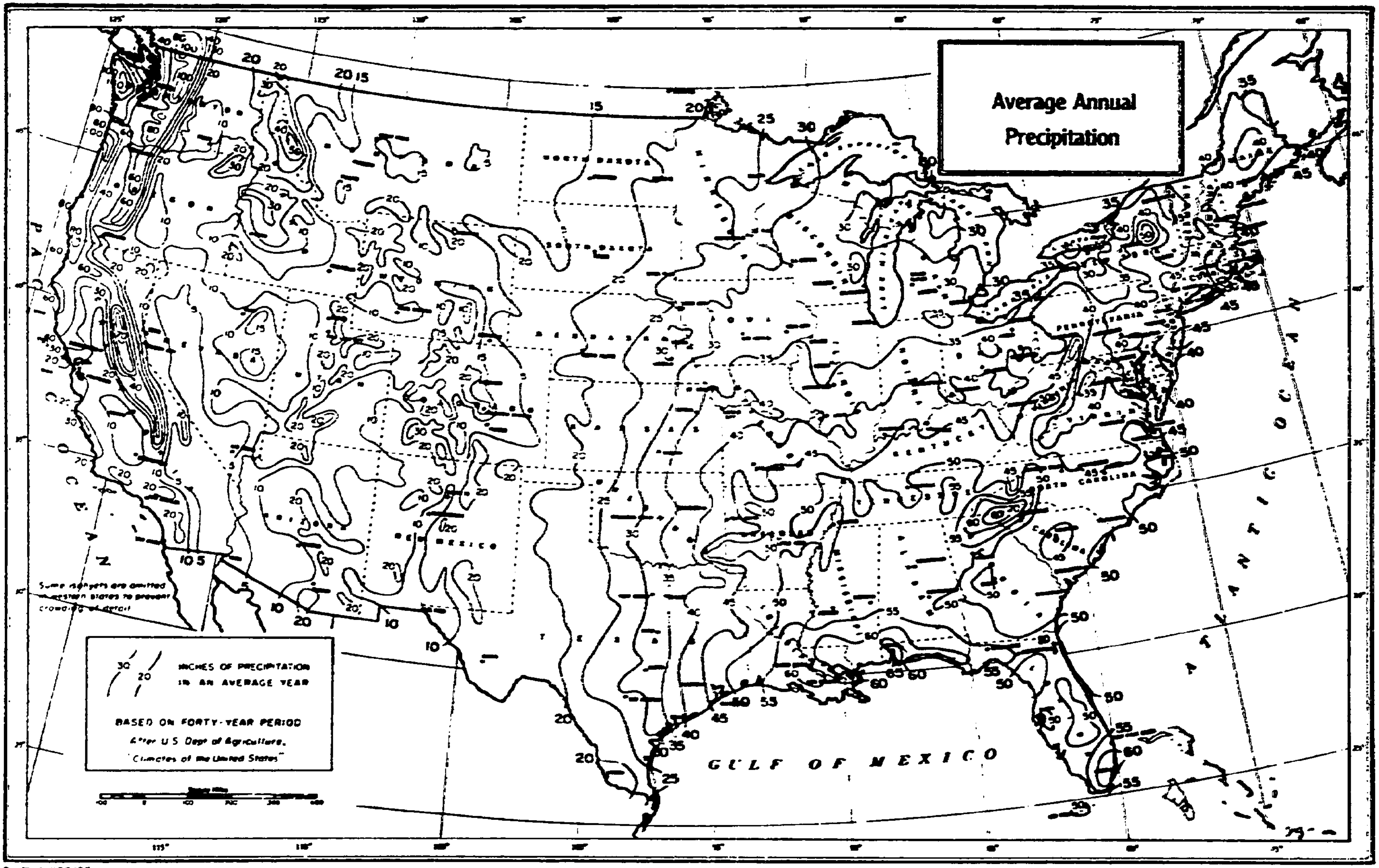
The average annual precipitation in the United States, expressed in inches, is shown in Figure C.2 (10). A similar indication of the average annual snowfall appears in Figure C.3. Although precipitation is the basic source of fresh water (other sources such as desalinization being comparatively minute), a large percentage of the precipitation evaporates before it can be collected and used by man. The water appearing as streamflow is more indicative of the amount of water available for use. The average annual streamflow or runoff expressed in equivalent inches of depth is shown in Figure C.4. This includes surface runoff as well as water flowing into the streams from ground water.

While the average annual runoff is a measure of the total surface water supply available, the distribution of runoff throughout the year determines the amount of storage required for a dependable water supply. For example, if all the runoff occurred in one month, no supply would be available for 11 months unless storage facilities were provided to impound sufficient water for the remainder of the year. Figure C.5 illustrates a typical hydrograph such as is used to determine storage requirements.

Man has practically no control over the hydrologic cycle although minor weather control attempts have been made. However, as illustrated by Figure C.6, he does interrupt the water cycle when he withdraws water from surface or ground water supplies, treats it to insure a safe supply and returns it to the surface or ground water.

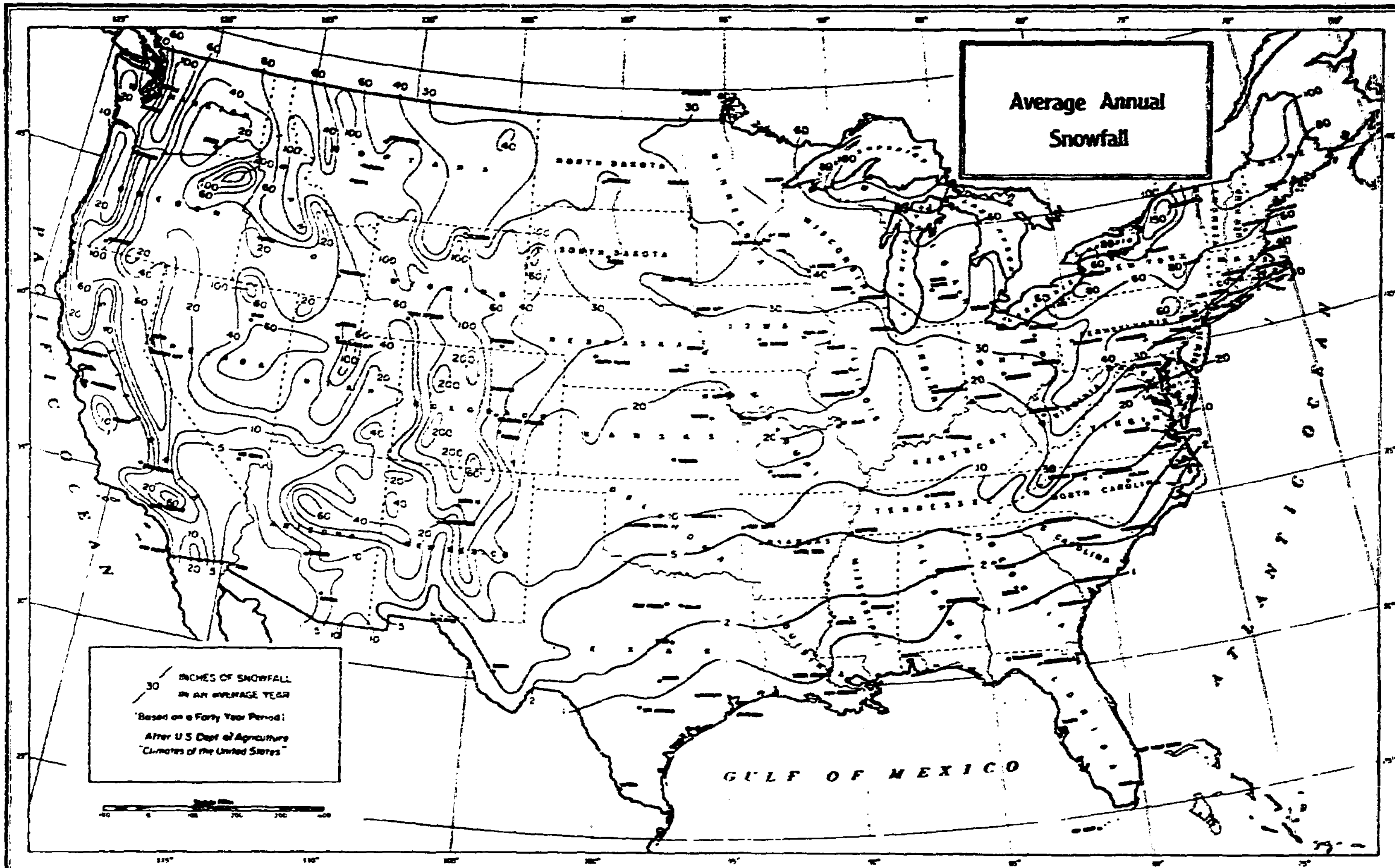
C.2 THE DEMAND FOR WATER

The demand for water may be considered to be divided into several categories; public water



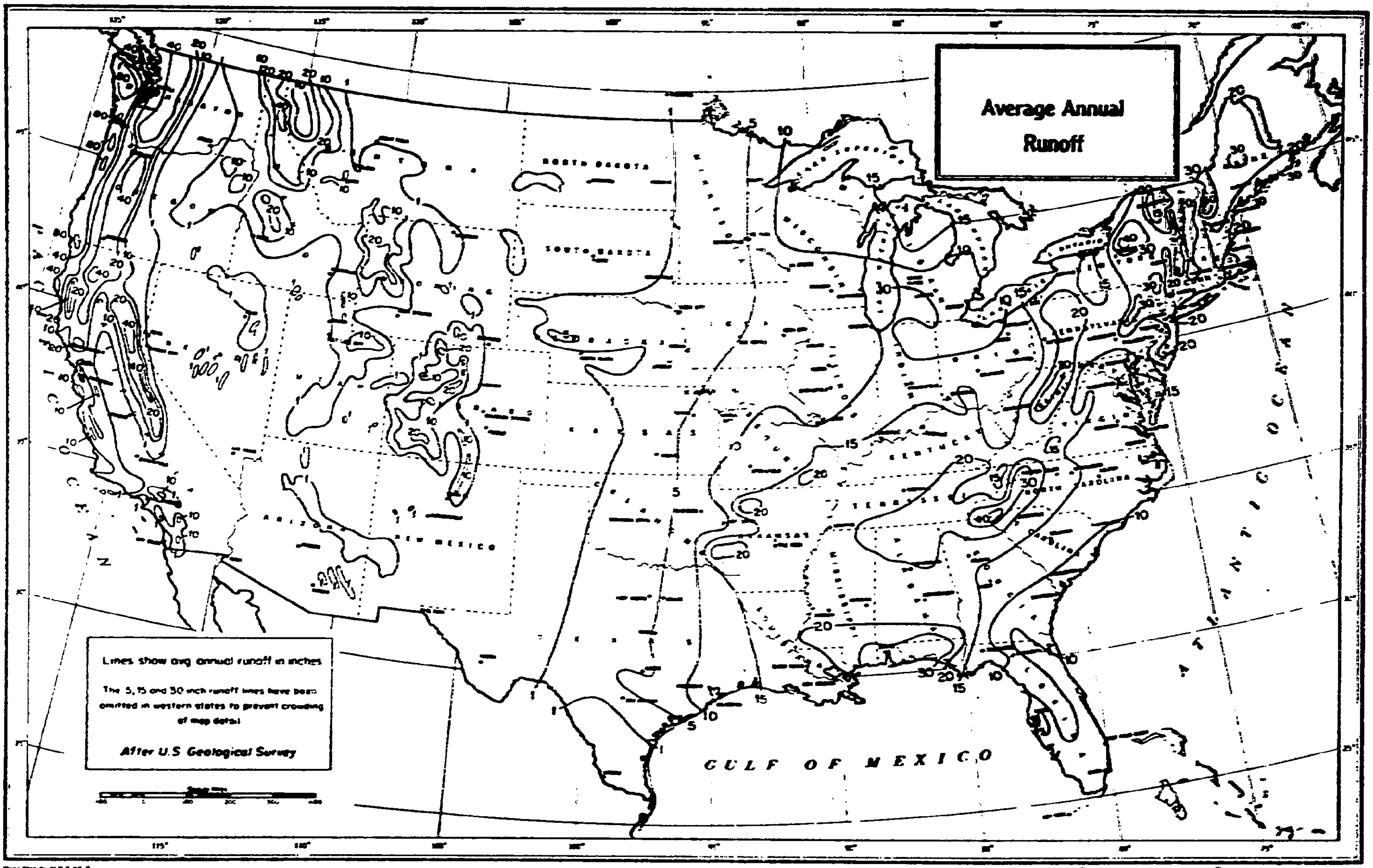
Courtesy of
Water Information Center Inc.

FIG. C.2



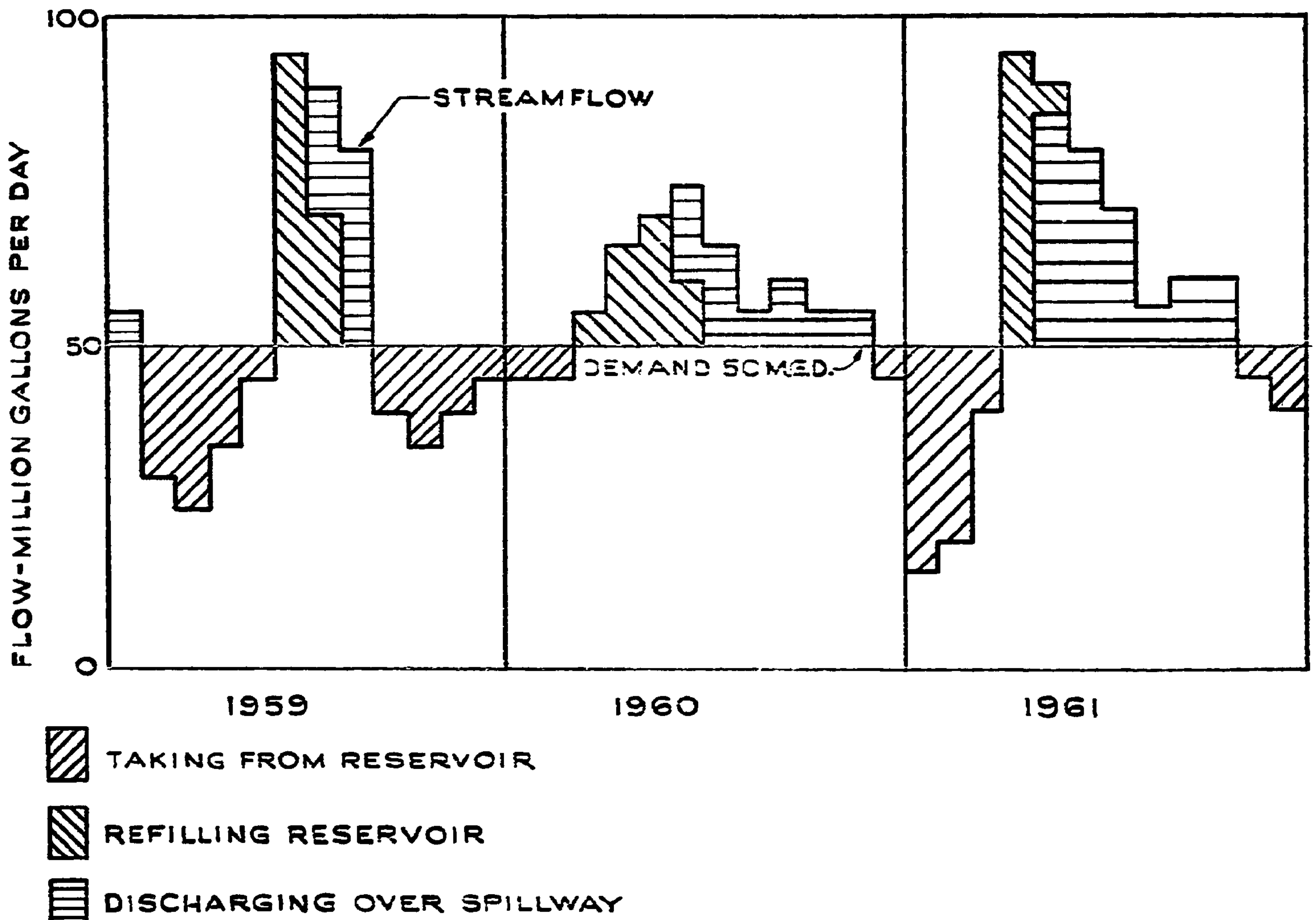
Courtesy of
Water Information Center Inc.

FIG. C3



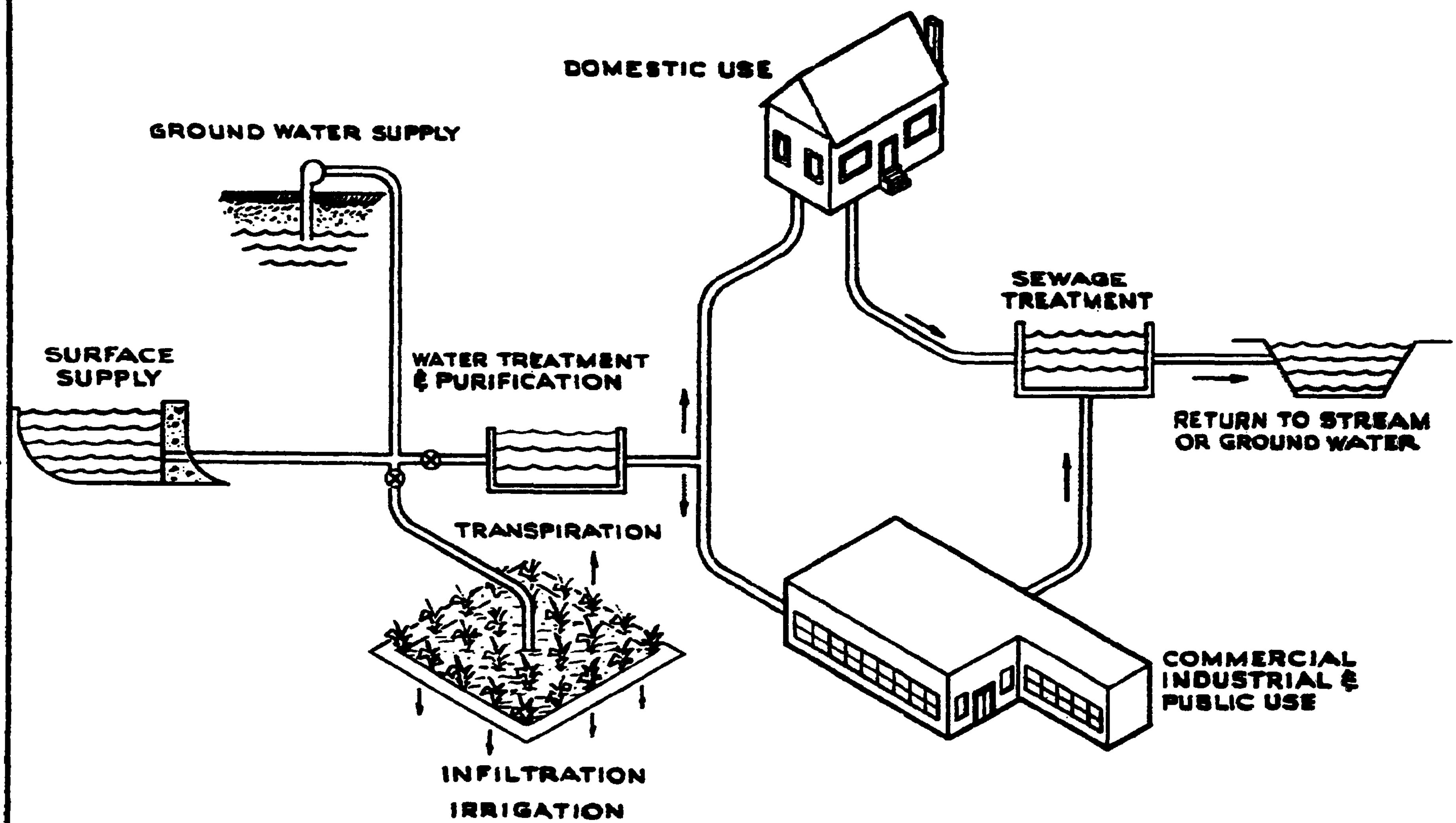
Courtesy of
Water Information Center Inc.

FIG. C4



STREAMFLOW HYDROGRAPH

FIG. C.5



INTERRUPTION OF THE WATER CYCLE

FIG. C.6

supply systems, industrial, irrigation, rural and water power. Water power is by far the largest user, withdrawing two million (2,000,000) gallons a day. However, this water is returned to the stream unimpaired and is not usually considered a demand in the statistical sense.

The amount of water withdrawn for other uses is indicated below.

Use	Million Gallons per Day
Public water supply systems	21,000
Industrial	140,000
Irrigation	110,000
Rural	3,600
TOTAL ---	274,600 Million Gallons Per Day

A portion of these quantities represents water which is used in more than one system.

Water use in public water supply systems varies from 100 to 250 gallons per capita per day. The average being about 147 gallons per capita per day. The demand for this water is divided as follows:

Use	Percent of Total
Domestic	41
Commercial	18
Industrial	24
Public	17

Domestic use includes water furnished to homes for personal needs. Typical minimum desirable peacetime quantities of water required for various uses is as follows: (11)

Use	Minimum Desirable Peacetime Requirement in Gallons Per Capita Per Day
Drinking and Culinary	4
Laundry	6
Bathing	5
Toilet	5
TOTAL ---	20

These are minimum desirable quantities and when augmented by other uses such as lawn sprinkling, and car washing the average minimum demand for domestic purposes is about 60 gpcd.

Commercial use includes that water utilized in office buildings, department stores, etc., and includes air conditioning make-up water.

The industrial use indicated here is only that portion served by public water supply systems as opposed to self-supplied industry discussed in Section C.6 Industrial demands are tremendous. For example, 18 gallons of water are used in the production of one barrel of oil and 300 gallons of water per barrel of beer. (12)

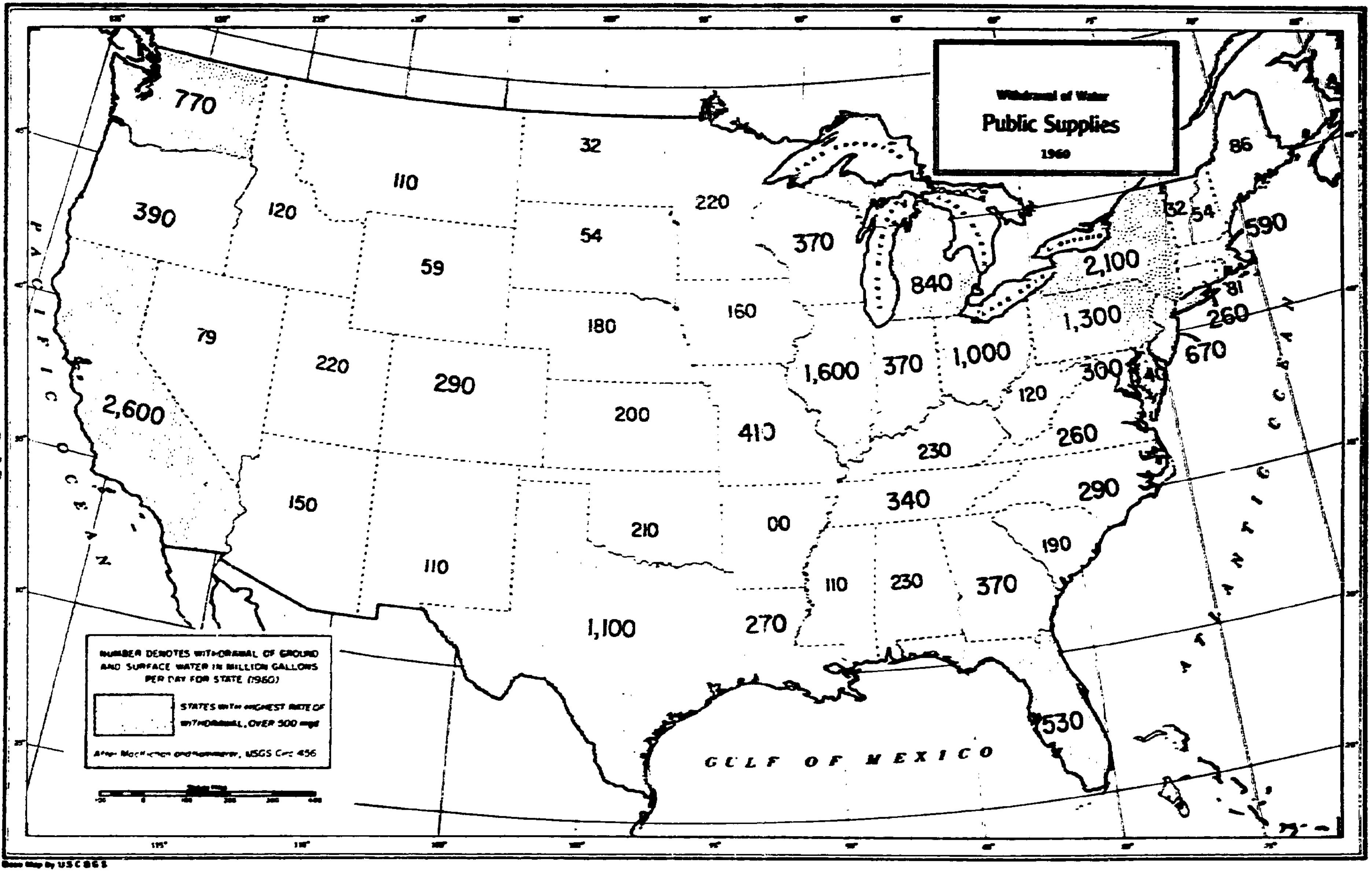
Public use includes that water furnished to city halls, schools, jails, etc., as well as the water used for cleaning streets and for fire protection. The quantity of water used for fire fighting is usually a small portion of the total annual use, but the short time fire fighting requirements often determine the capacity of pumps, distributing reservoirs and mains. Detailed requirements for fire fighting are published by the National Board of Fire Underwriters and are based upon such factors as population density, type of construction, water availability, etc. A population of 200,000, for example, requires a fire flow of 12,000 gallons per minute above the normal demand and a fire reserve storage of 7.6 million gallons.

Obviously there is a variation in demand for water in public systems from season to season. Warm weather increases the amount of water used for bathing, lawn sprinkling, air conditioning, car washing and swimming pools. Cold weather may stimulate the use of flowing water to prevent the freezing of pipes. Daily living habits also produce variations in the demand for water throughout the week. Variations in demand throughout the day are common, with peak demands around 7 o'clock in the morning and 7 o'clock in the evening. Each community has its own peculiar variations which must be determined individually. The maximum daily demand is about 1.5 times the average daily demand. The maximum hourly demand is about 2.5 times the average hourly demand.

The withdrawal of water by public supplies in 1960 is shown in Figure C.7, and the withdrawal of water by industries which own and operate their own water supply systems is shown in Figure C.8. About 71 percent of this water was used in fuel-electric power generating plants. About 94 percent of all the water used in this category was for cooling, approximately 25 percent of which was saline.

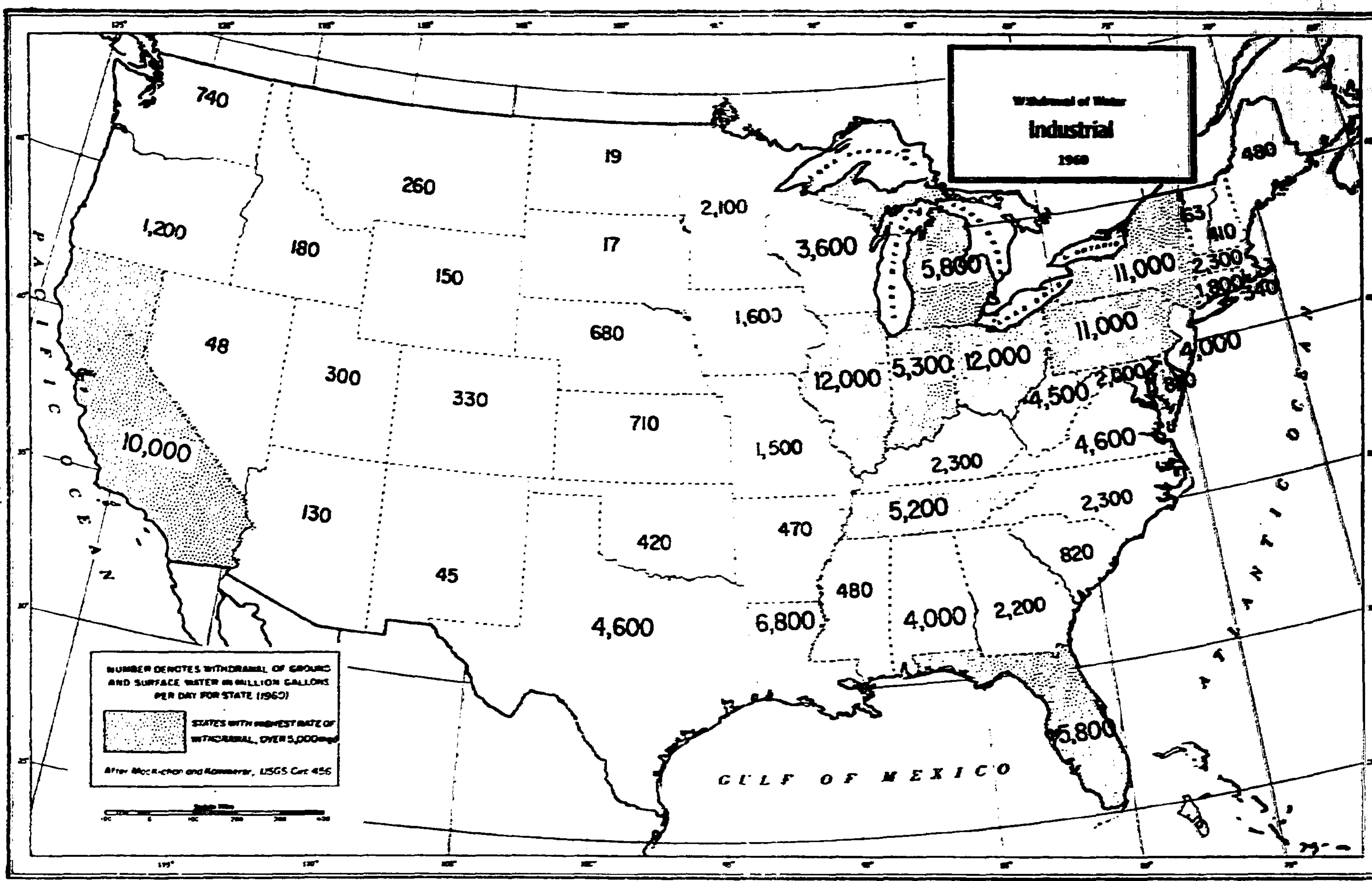
The use of water for irrigation is indicated in Figure C.9. An important consideration is that 60 percent of the irrigation water is evaporated or utilized by vegetation and is not available for further use.

The withdrawal of water for rural supplies is indicated in Figure C.10. Rural in this instance connotes those areas not served by public water supply systems. Approximately 1,600 million gallons per day are used for livestock and 2,000 million gallons per day for domestic purposes.



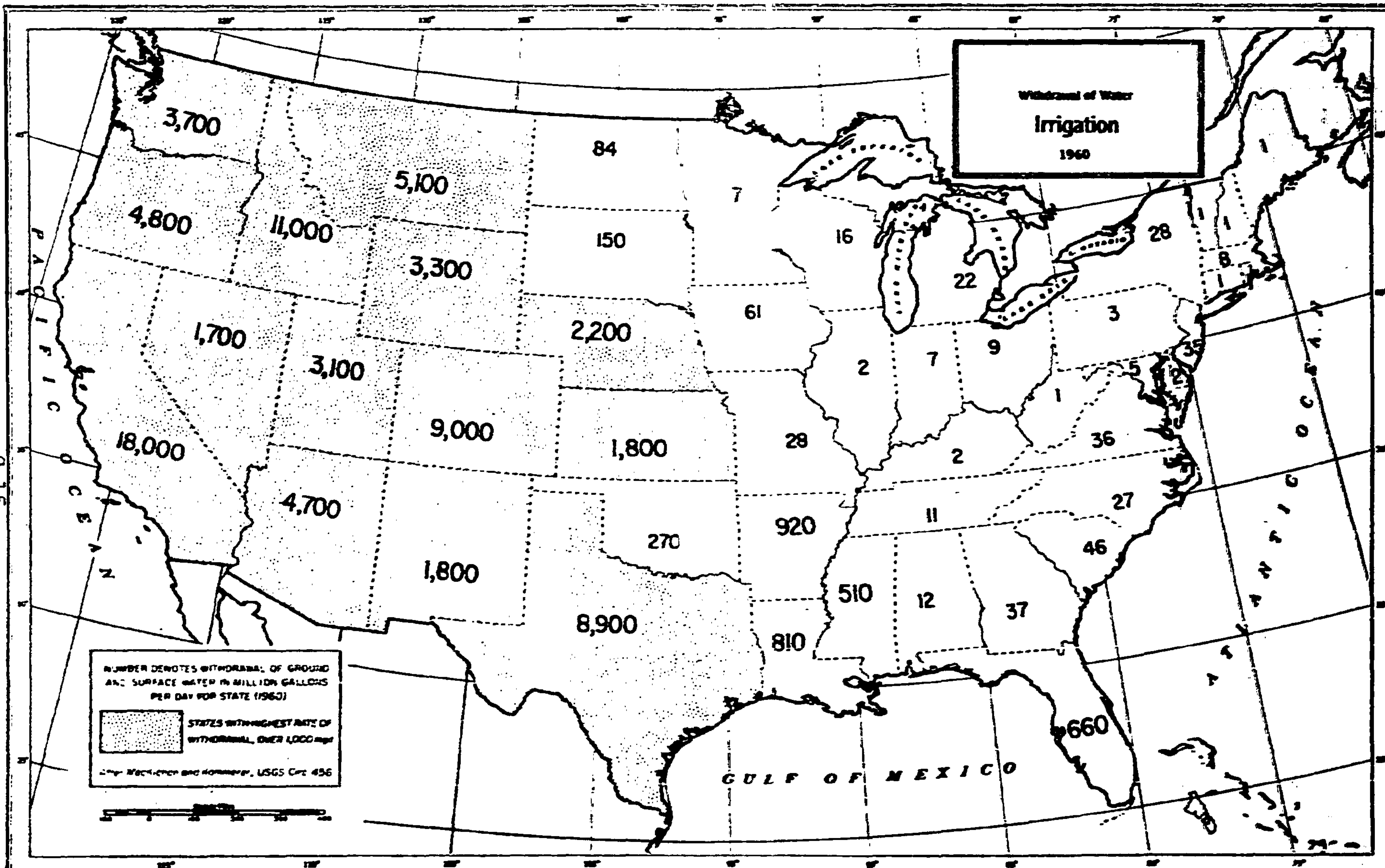
Courtesy of
Water Information Center Inc.

FIG. C.7



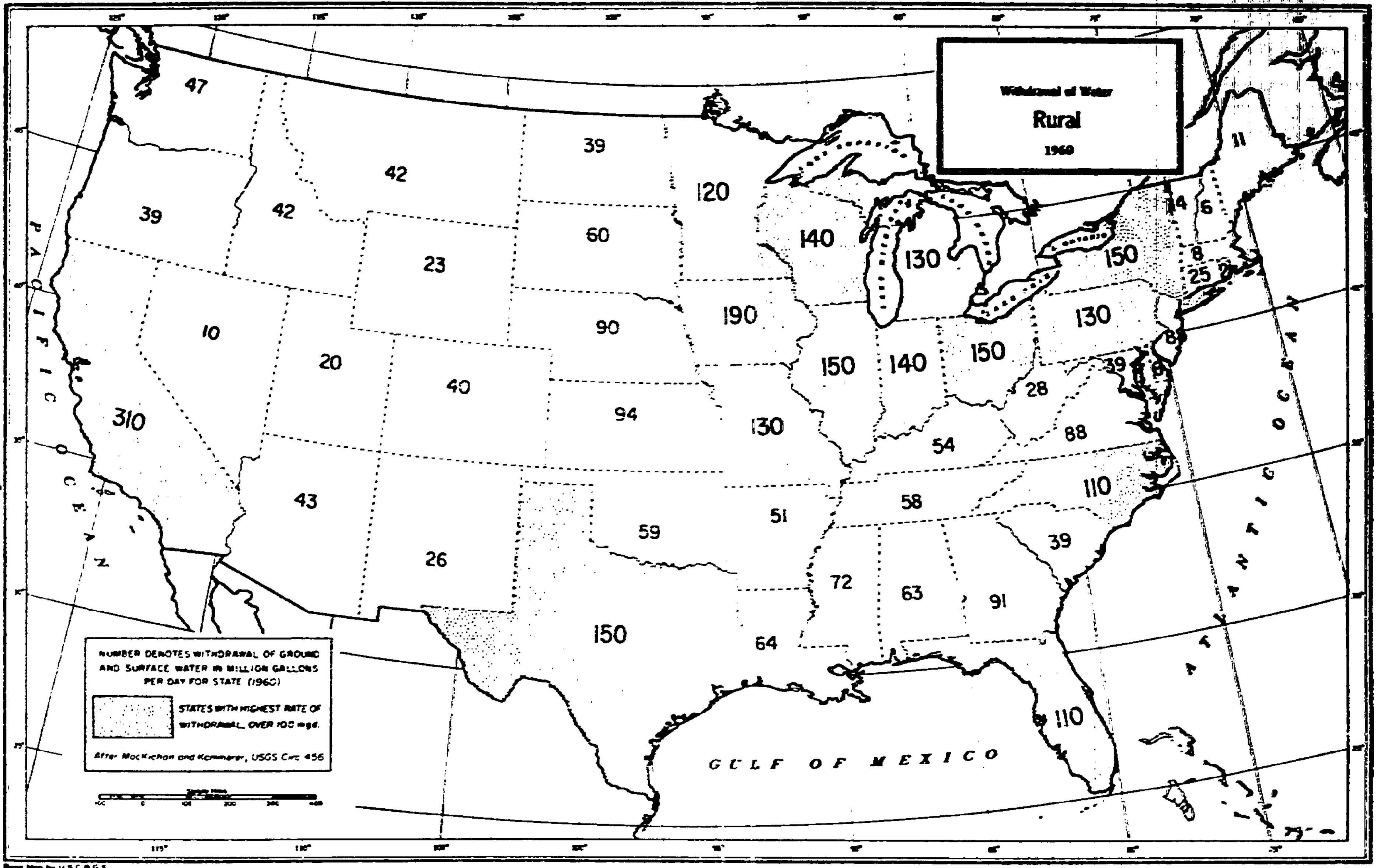
Courtesy of
Water Information Center Inc.

FIG. C.8



Courtesy of
Water Information Center Inc.

FIG. C9



Courtesy of
Water Information Center Inc.

FIG. C.1C

About 2,800 million gallons per day were obtained from wells and springs, and about 800 million gallons per day from streams and other surface supplies. Approximately 26 percent of the total United States population has private water supply systems.

Water for livestock, although a small percentage of the total consumption, is extremely vital. Average requirements for several animals are as follows:

Animal	Water Consumption in Gallons Per Day
Horse	10
Beef Cattle	10
Hog	4
Sheep	3
Milk Cow	15

C.3 COLLECTION OF WATER

Water supplies are categorized according to their source as being either ground water supplies or surface water supplies. Of course, water may flow from ground water to stream and then back to ground water. It is the nature of the supply at the point of withdrawal that labels it as a surface or ground water supply. Other sources such as desalinization or rain water collection are relatively insignificant in quantity when compared to these two sources and will not be considered here.

C.3.1 Collection of Surface Water Supplies

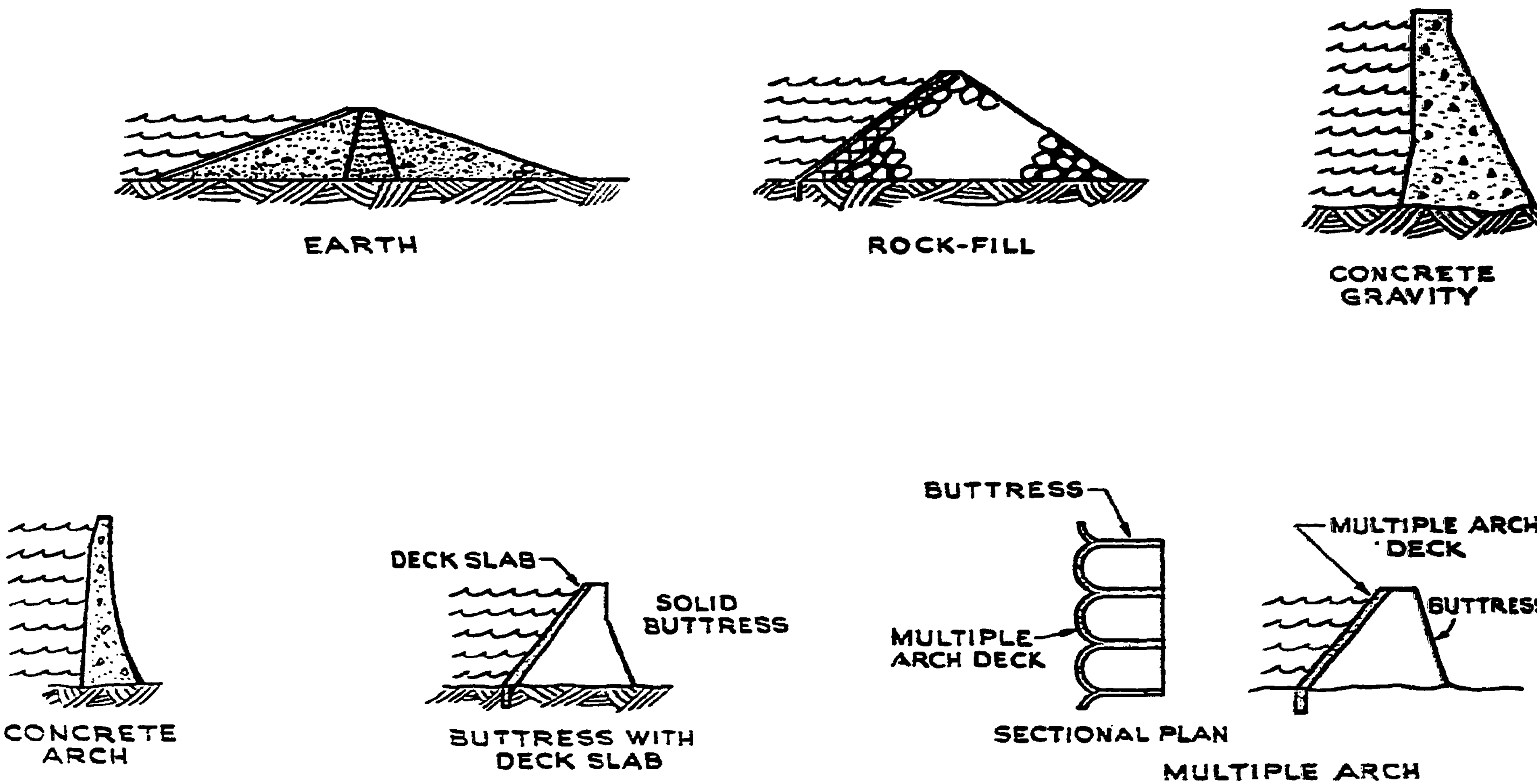
Surface water supplies are withdrawn directly from streams, rivers, lakes and other bodies of water. Depending on the quantity of water available, storage facilities may be constructed to average out seasonal fluctuations and to insure a year-round continuity of supply. Generally, these facilities are created by the construction of a dam across the stream or river, forming an impounding reservoir. The portion of precipitation flowing into this reservoir (runoff), and the land area contributing runoff to the point of withdrawal (watershed area) are the two most significant factors which establish the quantity of available water and the requirements for storage.

Storage facilities tend to be quite large in area and therefore are usually unlined and uncovered. However, in certain instances, they are lined with a waterproof membrane to reduce leakage or covered with various arrangements, including emulsions, to reduce loss by evaporation.

Types of dams vary from small earth or timber structures to massive concrete mammoths such as Hoover Dam (13). Some basic types are illustrated in Figure 4.11. Since these structures must be protected against damage during periods of high flow, spillways are often incorporated to permit the excess water to continue to flow downstream. These spillways, some types of which are shown in figure C.12, may also serve to provide a continual supply of water to downstream consumers.

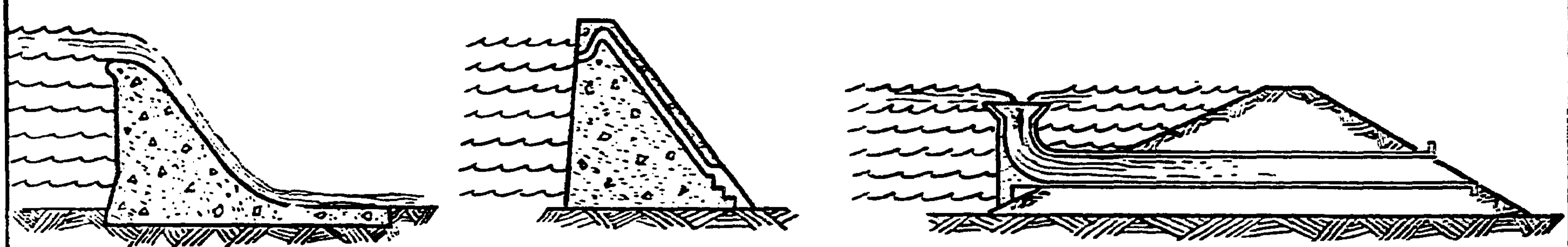
Water is withdrawn from the lake or reservoir through specially designed intake structures and conveyed to the water plant or distribution system. The intakes vary from simple submerged pipes to elaborate structures providing living quarters for operators. They may be incorporated in the dam or constructed in the reservoir or along the shore line. Submerged intakes are usually less costly and do not provide an obstacle to navigation. However, they do not provide the flexibility of the tower intakes which are usually provided with screens, control gates and valves. These may be operated to draw off water at various levels permitting selection of water of the optimum temperature and quality. Movable intakes which travel to follow fluctuating water levels in the reservoir are sometimes necessary. Two simple types of intakes are illustrated in Figure C.13.

Conduits leading from the reservoir may be lined or unlined canals; or enclosed pipes, tunnels or aqueducts. Flow may be under pressure or follow the hydraulic gradient. These conduits, some of which



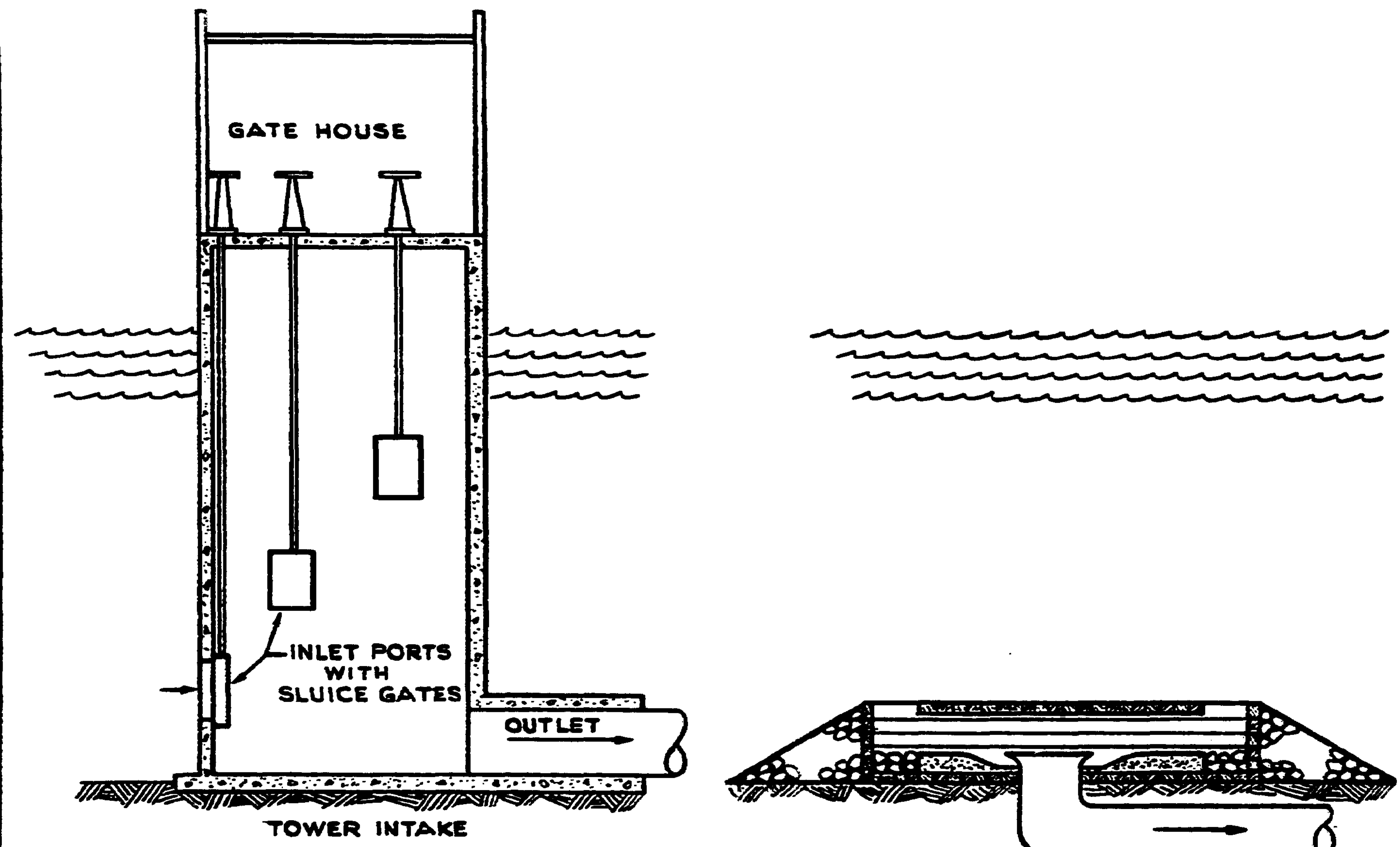
TYPICAL DAM SECTIONS

FIG. C.8



TYPICAL SPILLWAY SECTIONS

FIG. C.12



INTAKE STRUCTURES

FIG. C-13

are depicted in Figure C.14, are often large structures which carry water many miles from the reservoir to the distribution system or treatment plant and represent a considerable financial investment.

One type of surface water supply system is shown in Figure C.15.

C.3.2 Collection of Ground Water Supplies

The ground water supply may be thought of as an underground reservoir containing sand, gravle or porous stone in which the pores are filled with water. Ground water is not universally distributed, but depends upon the existence of favorable hydrologic and geologic conditions. Figures C.16 and C.17 indicate the major ground water areas in the United States. These maps indicate where productive aquifers of wide areal extent can be found; but do not indicate the quantity of water available from a specific tract of land, nor practicality of extraction.

A spring occurs where the ground water table intersects the surface. This water can be collected without pumping and used for small supply systems (Figure C.18a).

Artesian systems occur when ground water is trapped between two impervious layers under pressure. A well tapping an artesian supply will flow without pumping. Springs or artesian wells are the exceptional case, however, and it is usually necessary to provide a well to collect the ground water and a pump to raise it to the surface.

Dug wells are usually used for relatively small supplies in shallow aquifers. They may be dug by hand or mechanical equipment and are usually from 3 to 4 feet in diameter and from 30 to 50 feet deep. Larger and deeper wells are occasionally constructed for small towns. The wells are usually lined if constructed in earth but may be unlined in rock. The lining may be poured concrete, concrete pipe, concrete block, brick or other masonry construction.

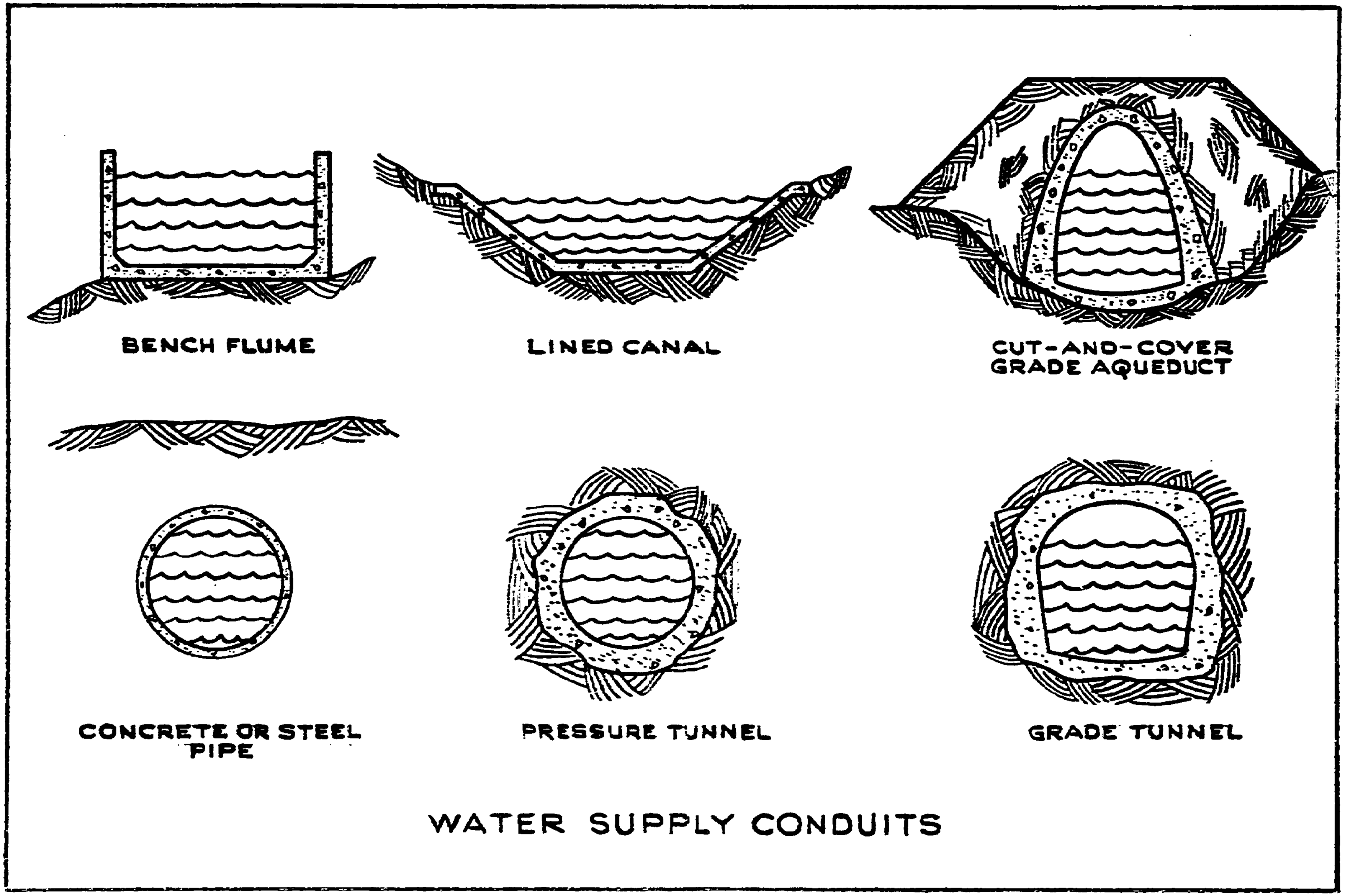
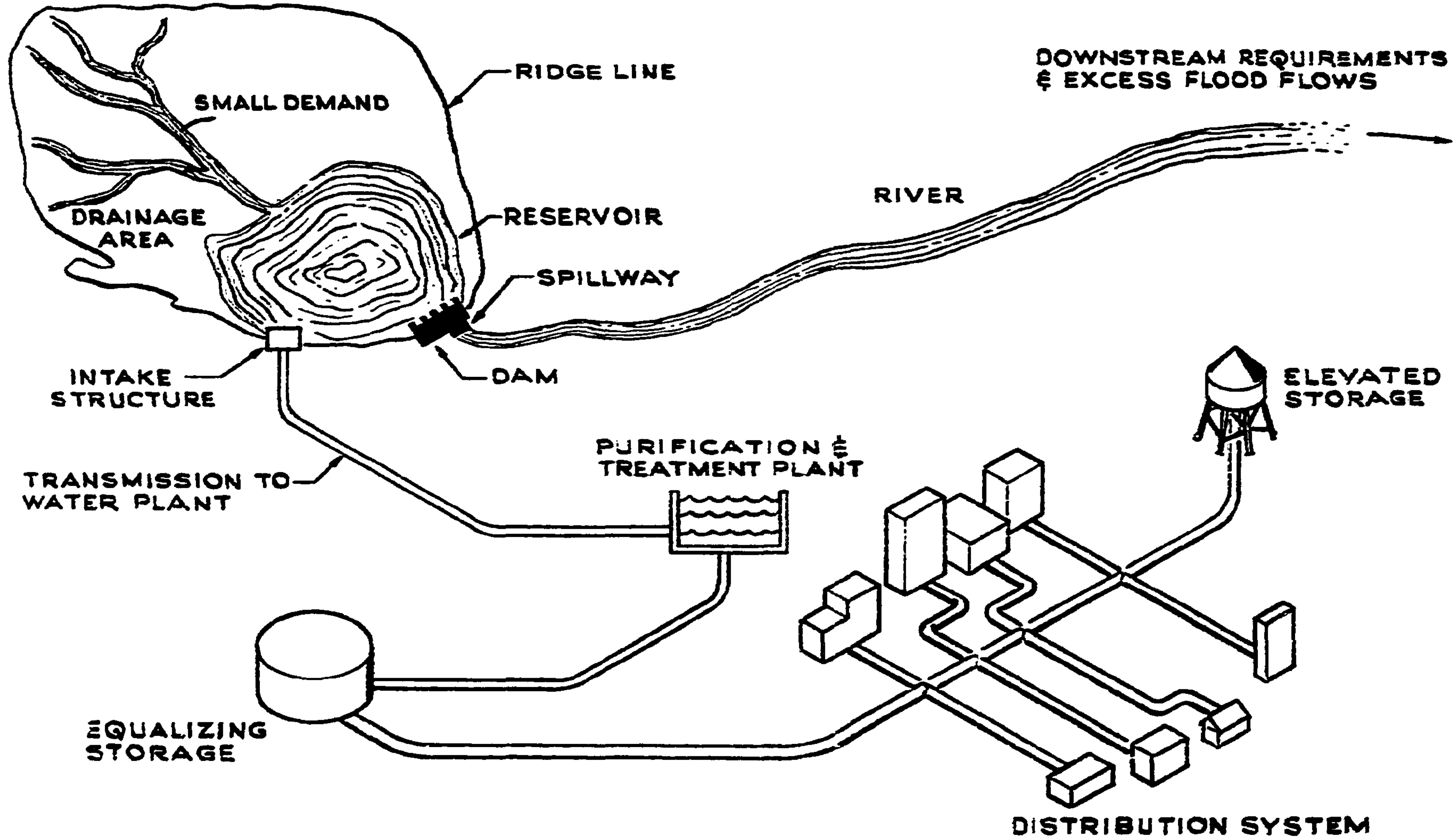

BENCH FLUME
LINED CANAL
CUT-AND-COVER GRADE AQUEDUCT
CONCRETE OR STEEL PIPE
PRESSURE TUNNEL
GRADE TUNNEL
WATER SUPPLY CONDUITS

FIG. C14

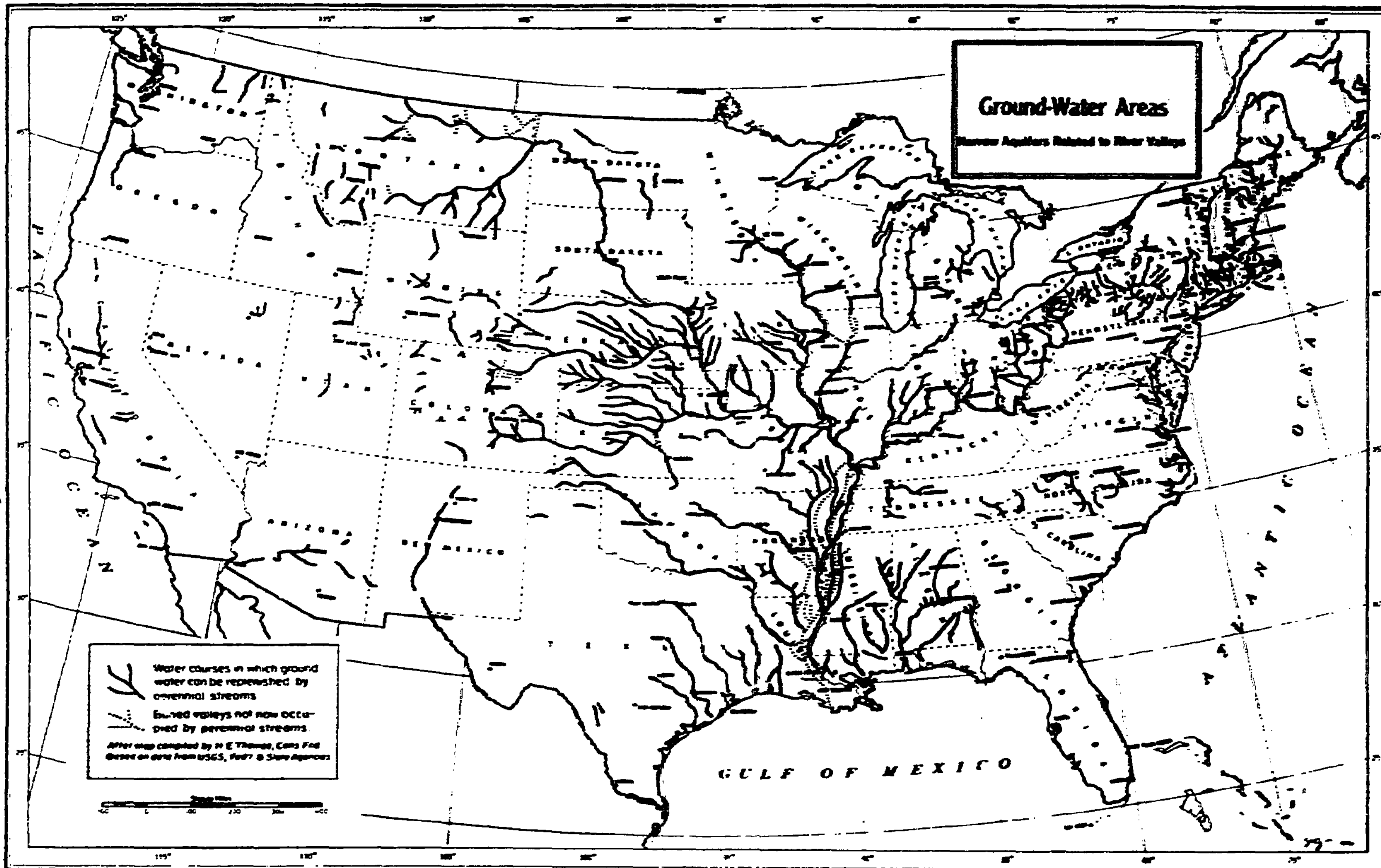


SURFACE WATER SUPPLY SYSTEM

FIG. C.15

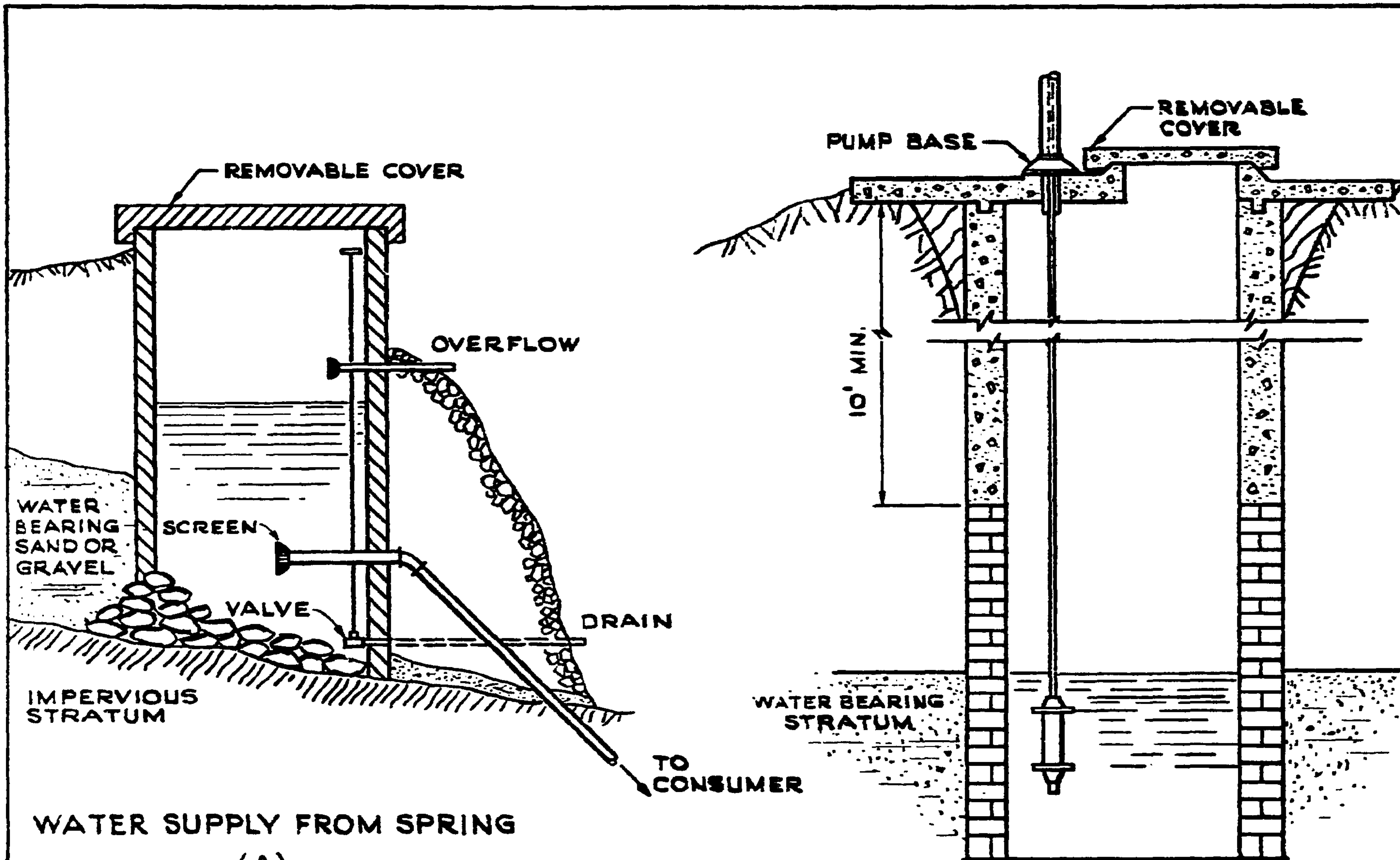
Courtesy of
Water Information Center Inc.

FIG. C.16



Courtesy of
Water Information Center Inc.

FIG. C.17



WATER SUPPLY FROM SPRING
(A)

DUG WELL
(B)

FIG. C.18

The bottom portion of the wells may be constructed with open joints to permit water to flow into them. Every precaution is taken in properly constructed wells to prevent surface water from seeping into the well and causing water pollution (Figure C.18b).

Driven wells are used for small supplies in shallow sand formations. A point at the bottom of a 1 to 3 inch diameter pipe facilitates driving (Figure C.19a). Water enters through a screen and is pumped to the surface, frequently by a centrally located horizontal centrifugal pump serving several wells in the well field.

Drilled wells are the most common type for municipal supplies. They usually tap high quality ground water several hundred feet below the surface. A metal casing is driven as the hole is drilled to prevent the sides from caving in. Typical capacities are 50 gallons per minute for a 6-inch diameter well and 3000 gallons per minute for a 24-inch well.

Hand operated reciprocating pumps are sometimes used for private water supplies, but power driven pumps are used for all municipal wells as well as for many private wells. Power driven reciprocating pumps are generally used for deep wells of small capacity.

The usual municipal installation consists of a vertical turbine pump for each well (Figure C.20). The pump may be driven by an electric motor or gasoline or diesel engine mounted directly above the well. The impellers are mounted on the shaft near the bottom of the well. Water from the aquifer enters the well through a strainer which may be surrounded by gravel. The water flows through a series of impellers, each of which serves to increase the pressure. As many as 20 impellers may be used depending upon the total depth and head required (14).

A submersible pump in which the motor and pump are combined in a close coupled unit and suspended in the well by the discharge pipe can be used in crooked

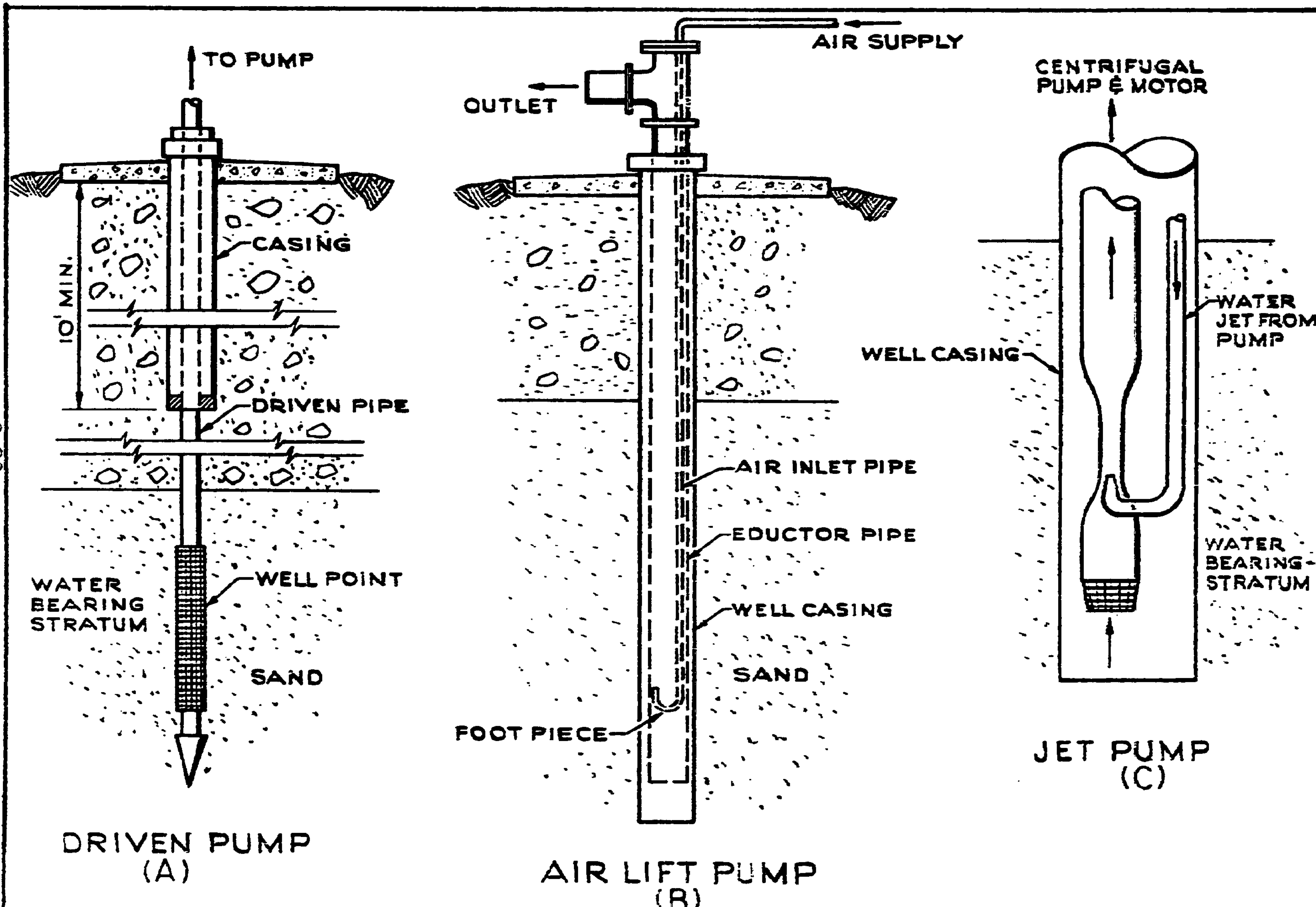
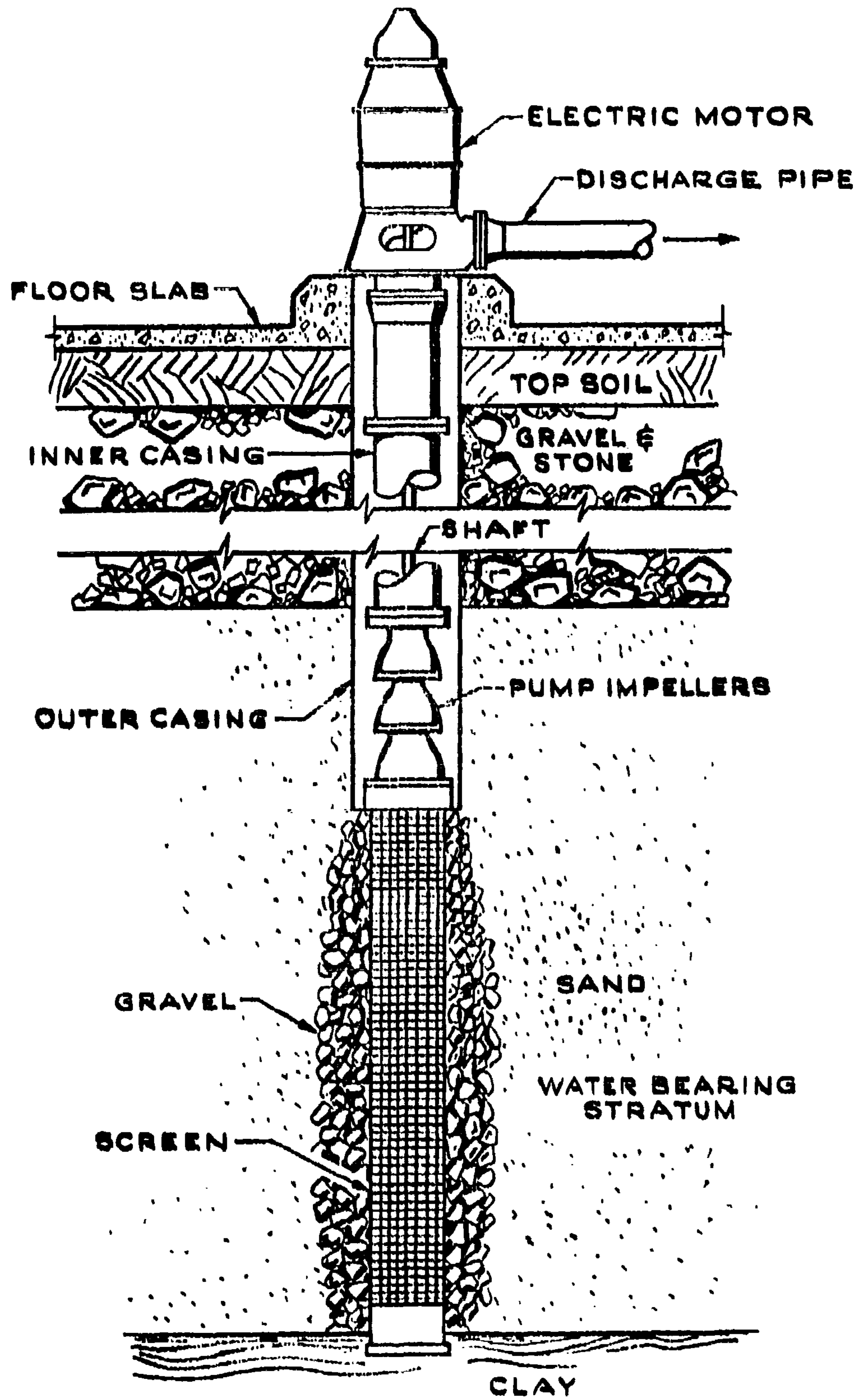

TO PUMP
CASING
10' MIN.
DRIVEN PIPE
WELL POINT
WATER BEARING STRATUM
SAND
DRIVEN PUMP (A)
AIR SUPPLY
OUTLET
AIR INLET PIPE
EDUCTOR PIPE
WELL CASING
SAND
FOOT PIECE
AIR LIFT PUMP (B)
CENTRIFUGAL PUMP & MOTOR
WELL CASING
WATER JET FROM PUMP
WATER BEARING-STRATUM
JET PUMP (C)

FIG. C.19



GRAVEL-PACKED WELL WITH TURBINE PUMP

FIG. C. 20

or straight wells for heads up to 1500 feet. They are normally used in wells from 6-inches to 24-inches in diameter with capacities up to 20,000 gpm.

Air-lift pumps (Figure C.19b) may be used in crooked or straight wells of any size and depth. They are simple and have no moving parts in the well. Compressed air is pumped into the well through a foot piece. The rising bubbles form a mixture of air and water which has a lower specific gravity than the water in the aquifer. The unbalanced hydrostatic pressure causes water in the eductor pipe to rise to the outlet. The air-lift pump requires a deeper hole to provide proper submergence of the air outlet, and efficiencies are relatively low varying from about 20% to 45%.

Jet pumps are widely used in low capacity installations up to about 70 gpm (Figure C.19c). It is operated by a motor and centrifugal pump at the ground surface and a jet in the well. The centrifugal pump has two discharge pipes. One pipe carries water into the well where it is discharged at high velocities into a constricted section of the discharge pipe. This creates a partial vacuum which draws water from the aquifer and carries it to the suction side of the centrifugal pump. The second discharge from the centrifugal pump carries the water into the distribution system or storage tank.

C.4 WATER TREATMENT

From its contact with the earth and the atmosphere, water absorbs various impurities. The primary purpose of treating water is to remove those impurities injurious to public health, but it may also be treated for aesthetic, economic, industrial or other reasons. Common impurities found in water and their effects are indicated in Table C.1 (15). The U. S. Public Health Service publishes standards for the quality of water on interstate barriers limiting the amounts of contained impurities. These standards have been voluntarily adopted by most public water supply systems.

Category	Group	Subgroup	Impurity	Effect
Suspended impurities			Bacteria	some cause disease
			Algae, protozoa	odor, color, turbidity
			Silt	murkiness or turbidity
Dissolved impurities	Salts[1]	Calcium and magnesium	bicarbonate	alkalinity, hardness
			carbonate	alkalinity, hardness
			sulfate	hardness
			chloride	hardness, corrosive to boilers
		Sodium	bicarbonate	alkalinity, has softening effect
			carbonate	alkalinity, has softening effect
			sulfate	foaming in steam boilers
			fluoride	mottled enamel of teeth
			chloride	taste
			Iron oxide	taste, red water, corrosive to metals, hardness
			Manganese	black or brown water
			Vegetable dyes	color,[2] acidity
	Gases		Oxygen	corrosive to metals
			Carbon dioxide	corrosive to metals, acidity
			Hydrogen sulfide	rotten-egg odor, acidity, corrosive to metals
			Nitrogen	

[1] Salts cause tastes if present in large amounts.
[2] Strictly speaking color is caused by material in a colloidal state.

TABLE C.1 - COMMON IMPURITIES OF WATER *

*From Ernest W. Steel, "Water Supply and Sewerage," 1953.

Each potential water supply must be analyzed, and the type of treatment determined based on the quality of the raw water and the desired quality of the treated water. Several basic procedures are common to all treatment plants, but these are used in various combinations to meet the particular needs. The usual unit operations are described below and illustrated in figures C.21 and C.22.

C.4.1 Screens

Bar screens or racks are used for removing coarse material such as branches or debris. These screens consist of round or flat metal bars spaced from 1" to 3" apart. Small installations may be cleaned by hand raking, but larger installations usually use power-driven cleaning rakes.

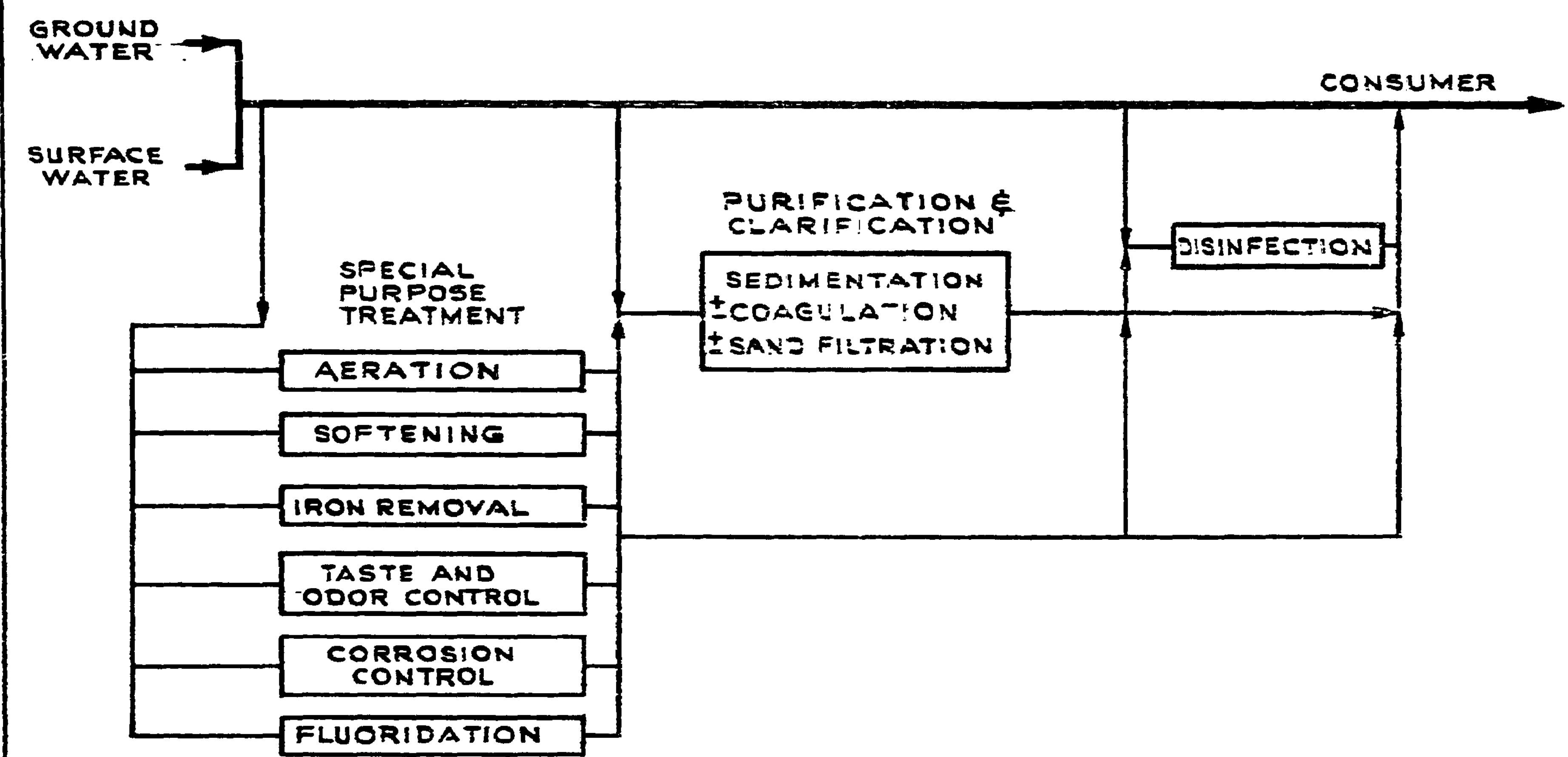
Stationary or traveling fine-mesh screens are used to intercept material passing the bar screens. 1/8" to 3/8" mesh is most common, but many varieties and sizes are available.

C.4.2 Sedimentation

One of the simplest methods of removing suspended matter from water is plain sedimentation. This is simply a time delay storage of raw water so that those suspended particles having density greater than water move to the bottom under the action of gravity. Modern sedimentation basins are usually continuous flow tanks and many be rectangular, square or circular. Sludge is usually pushed by slow-moving power-driven collectors to a hopper and disposed of.

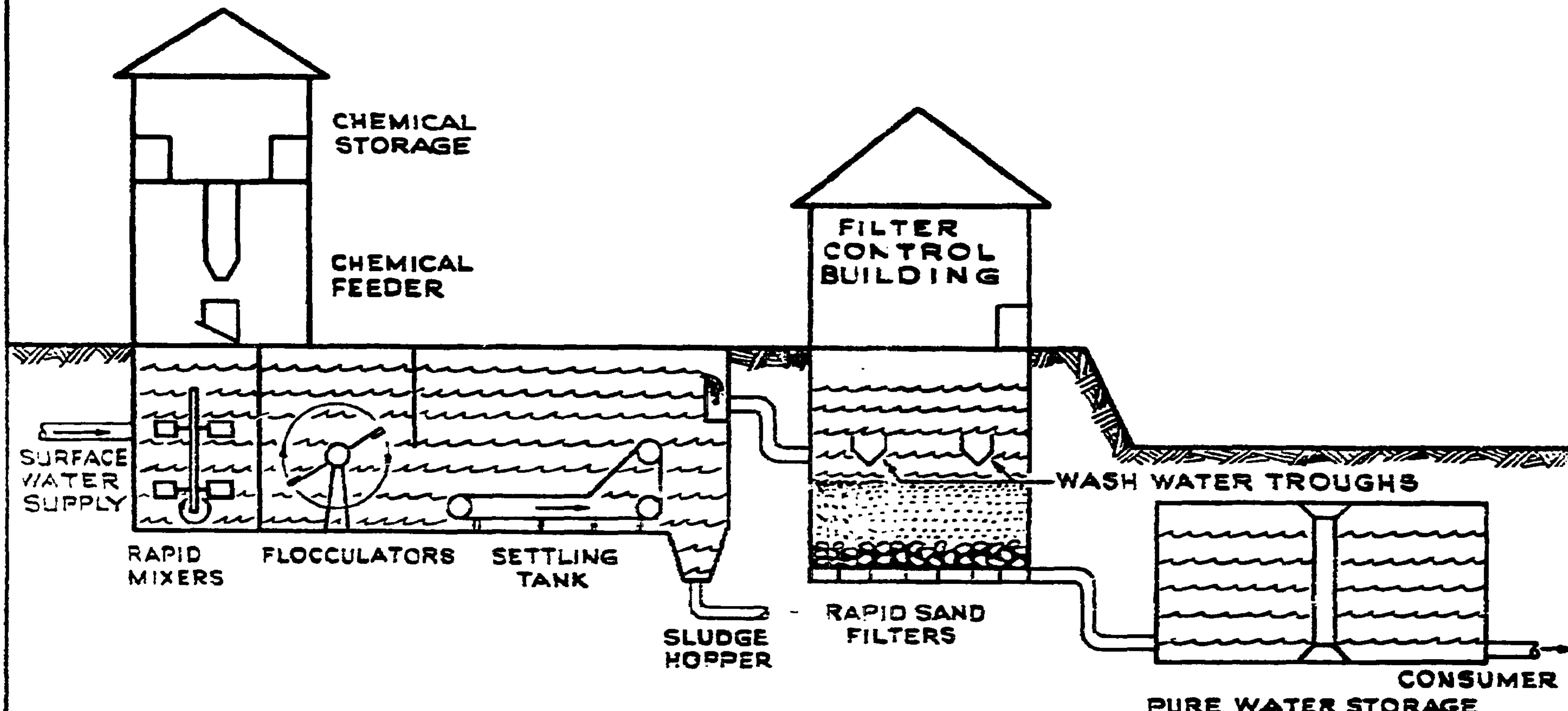
C.4.3 Coagulation - Sedimentation

The settling velocities of finely divided and colloidal clay are so small that plain sedimentation is impractical. Chemicals are therefore added to the water, rapidly mixed and then slowly stirred or flocculated to form a floc. This floc absorbs particles of turbidity, including colloidal clay and color, and also absorbs and entangles some bacteria.



WATER TREATMENT
COMBINATION OF PROCESSES

FIG. G.21



DIAGRAMATIC SKETCH OF PURIFICATION-CLARIFICATION PLANT

FIG. C.22

The large floc particles settle to the bottom where the sludge is collected.

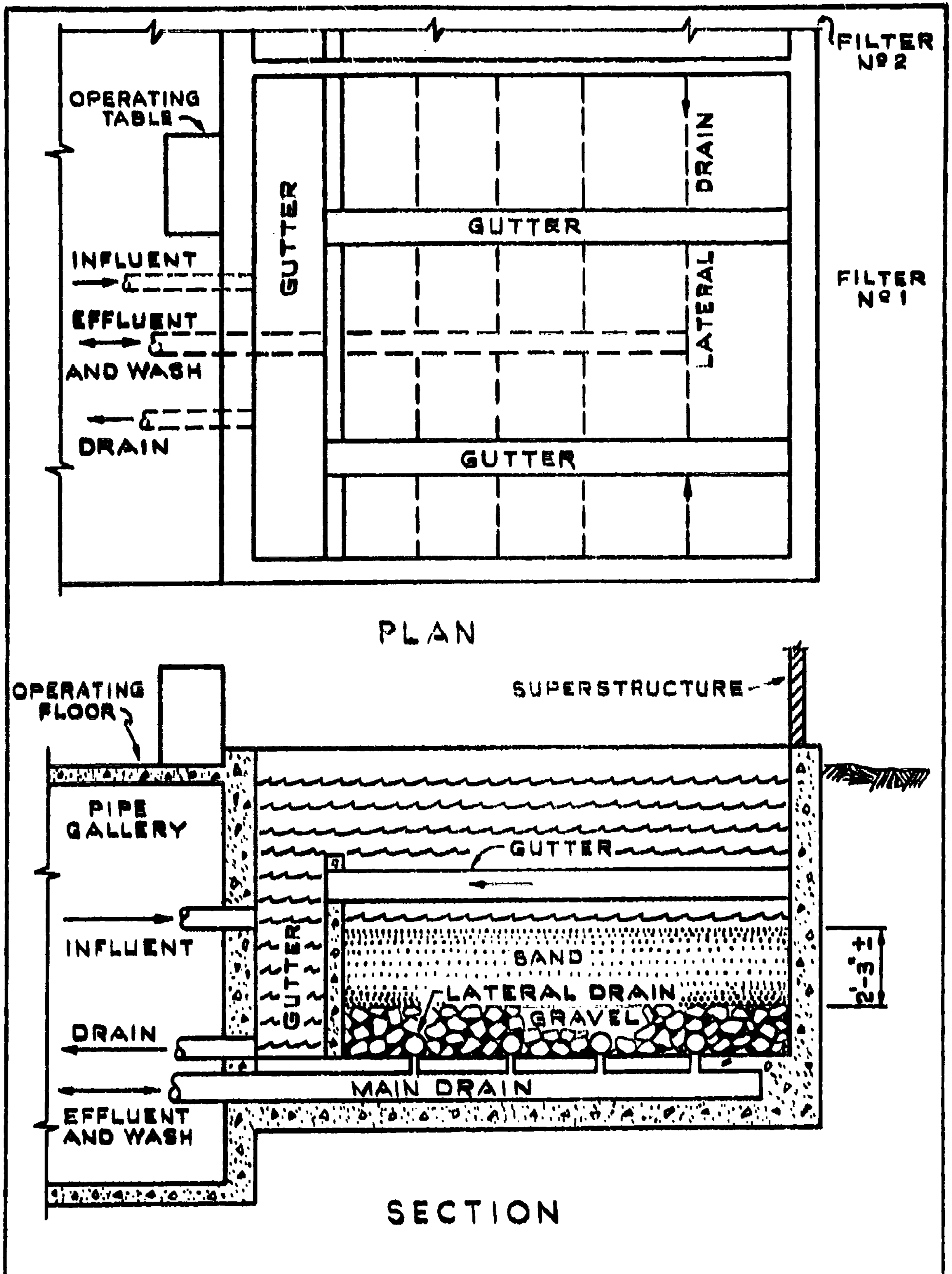
The most commonly used coagulant is aluminum sulfate or alum. Copperas or ferrous sulfate and lime are also used and to a lesser extent, ferric chloride, sodium aluminate and chlorinated copperas. Coagulation-sedimentation is usually used to reduce the turbidity and bacteria in the water which then goes to the filter for further treatment.

C.4.4 Filtration

Sand filters are used to produce a clear and sparkling water essentially free of harmful bacteria. Sand filters are effective in removing bacteria, finely divided clay and colloidal matter smaller than the openings between the sand grains. The sand acts as a strainer, but also removes matter which adheres to the sand particles as the water follows a circuitous path through the filter. Most filters use sand as the filtering media, but anthracite coal has been effectively used for this purpose. Diatomaceous earth is often used for smaller pressure filters and special applications such as swimming pools.

Slow sand filters utilizing 24" to 42" depths of sand can handle 3 or 4 million gallons per acre per day. The filter is cleaned by scraping off the top layer of sand at periodic intervals. This sand may be washed and re-used repeatedly.

Rapid sand filters have a sand depth of about 27" and can handle from 125 to 200 million gallons per acre per day (Figure C.23). The high rate is due to the fact that the sand is washed at frequent intervals by reversing the flow. The wash water moves up through the sand with sufficient velocity to clean the sand particles. Considerable quantities of water must be used and wasted for this purpose. A clear well or reservoir is usually located at the plant to store filtered water and permit a relatively constant rate of operation. Rapid sand filters are usually located in a building, frequently with a pipe gallery running along the longitudinal axis of the building, serving



DIAGRAMATIC SKETCH OF A RAPID SAND FILTER

FIG. C.23

filters on each side. Extensive piping, flow controllers, valves and provision for back-washing result in a complicated but effective means of treating water. The turbidity can be reduced to less than one part per million and the bacterial removal is about 90 percent.

C.4.5 Disinfection

Water is disinfected to kill the disease-causing bacteria which it may contain. Chlorine in its various forms is widely used for this purpose. Other methods of disinfection such as ozone, ultraviolet ray, excess lime and iodine are also used but only to a very limited extent.

Some surface waters of high quality require no treatment other than sedimentation and chlorination. Similarly, some ground waters may receive no treatment other than chlorination. Chlorine added at the influent of a filter plant has been found to improve coagulation and reduce tastes, odors and troublesome algae. Chlorine added as the final step in a filter plant is usually applied in dosages from 0.25 to 0.5 ppm. Prechlorination and postchlorination may be applied at the same installation if the raw water is highly polluted. In break-point chlorination, chlorine is added in large doses of 7 to 10 ppm (16). This technique has been found to remove tastes and odors; to have an adequate bacteriacidal effect and to leave a desired chlorine residual. In some cases ammonia added in combination with chlorine has been found to eliminate chlorophenal tastes and prolong the bactericidal activity.

Chlorine for public supplies is most often supplied in pressurized cylinders. The chlorine is in liquid form in the container but becomes gaseous upon release. The chlorine gas may be applied directly to the water, or a solution of water and chlorine may be formed and applied at the desired location. The rate of feed is usually automatically controlled by the chlorinators. Chlorine gas is extremely active and extreme precautions are taken to provide safe working conditions for plant personnel.

For small installations and for emergency use, chlorine may be applied to the water in the form of chlorinated lime or calcium hypochlorite containing about 30 percent chlorine. Modern installations use HTH or Perchloron containing 65% chlorine. These products come in powder or tablet form and are applied with dry feed machines or in solution form. The safety and ease of maintenance of hypochlorination make it preferable for many small installations.

C.4.6 Aeration

Aeration of water is practiced to remove hydrogen sulfide, carbon dioxide, simple chlorine and other odor or taste causing substances. It is also used in conjunction with trickling beds for iron and manganese removal.

Spray nozzles acting under pressure direct the water vertically upward in jet or spray form. The physical action permits the escape of undesirable gases and the absorption of oxygen. Cascades, a series of small waterfalls, provide a similar action. In trickling beds, the water is fed through perforated pipes and falls under gravity action through beds of coke, slag or stone. Air may be blown in through pipes or porous plates at the bottom of a tank containing water. The action of the rising bubbles has been found to be effective and may also be used for mixing chemicals.

C.4.7 Water Softening

Hard water is caused by the carbonates, bicarbonates, sulfates and chlorides of calcium and magnesium. The purposes of water softening are: (1) conservation of soap, (2) reduction of wear and tear on clothing being laundered and (3) prevention of scale formation in steam boilers. Softening also has secondary effects such as increasing the efficiency of filtration; aiding the removal of color, iron and manganese; assisting in the production of non-corrosive water; increasing the removal of bacteria and improving the cooking of foods.

The lime-soda method is usually employed for large scale municipal water supplies. Lime is effective in removing carbonate hardness, while sodium carbonate (soda ash) is used to reduce sulfate, chloride and non-carbonate caused hardness. Lime softening leaves water supersaturated with calcium carbonate which tends to clog filters and cause troublesome incrustation of pipes and meters. To prevent this, recarbonation is usually employed by passing carbon dioxide through the water. The procedure is followed by sand filtration to insure complete clarification.

The zeolite method of water softening is an ion-exchange process. The zeolites used in water softening are natural or synthetic compounds of sodium, aluminum and silica. When water containing calcium and magnesium compounds are passed through the zeolite, the calcium and magnesium are removed and exchanged for the sodium in the zeolite. The sodium content of the zeolite is regenerated as required by applying a solution of sodium chloride.

Zeolite softeners are usually operated as pressure units. The water is fed into a closed tank, passed through a bed of zeolite from 3 to 6 feet deep, and then discharged. Provisions are made for back washing and regenerating the zeolite.

Zeolite softening is used in industrial plants and cities but is not satisfactory for a water of high turbidity. The units are compact and easy to operate, and any desired degree of hardness adjustment can be made.

C.4.8 Removal of Iron and Manganese

Iron and manganese may be found in various forms in surface and ground waters but are more common in the latter. They cause taste and odors, reddening of the water resulting in staining of clothing and plumbing fixtures, and may cause corrosion. A variety of methods is used to remove iron and manganese from water depending upon the form in which it is found.

Aeration, or aeration and trickling beds followed by sedimentation and possibly sand filtration may be satisfactory. Aeration plus chlorination or chlorination plus sedimentation and filtration is also used. Another procedure consists of aeration and the addition of lime plus sedimentation and filtration. For well waters devoid of oxygen, a sodium zeolite unit is often used.

C.4.9 Corrosion Control

It is often desirable to treat water to reduce corrosion. Sodium silicate has been found to reduce corrosion by forming a protective coating on metal surfaces. It has been used primarily in industrial applications where it is added in initial doses of 20 ppm followed by reduced doses. Sodium phosphate or sodium hexametaphosphate in doses from 0.5 to 1.0 ppm are also used in corrosion prevention. Lime is added in an attempt to obtain carbonate balance or to reduce the concentration of hydrogen ions available to replace metallic ions. Various bacteria in water foster corrosion, and this bacteria may occasionally be controlled by the additional chlorine or chlorine and ammonia. The treatment may have adverse effects in some instances, however, and must be carefully controlled.

C.4.10 Chemical Taste and Odor Control

Taste and odors in water may be caused by dissolved gases, algae and other microorganisms; decomposing organic matter; industrial wastes and chlorine (free or in combination with phenol or organic matter).

Copper sulfate applied in lakes and reservoirs is effective in controlling algae growth, but an excessive dose may kill fish. Chlorine is also effective in algae control.

Carbon, prepared from saw dust, paper mill wastes or similar material, heated in a closed vessel and activated with air or steam has absorptive properties that make it useful for taste and odor control. Available in powdered or granular form, it can remove organic matter, chlorine, hydrogen sulfide and iron. It can be used in a fashion similar to that of gravity or pressure filters but is more frequently added at various points in the coagulation sedimentation - sand filtration process.

Chlorine dioxide, formed by adding a sodium chlorite solution to a chlorine solution, is a rapid oxidizing agent and is effective in some taste and odor control problems.

C.4.11 Fluoride Control

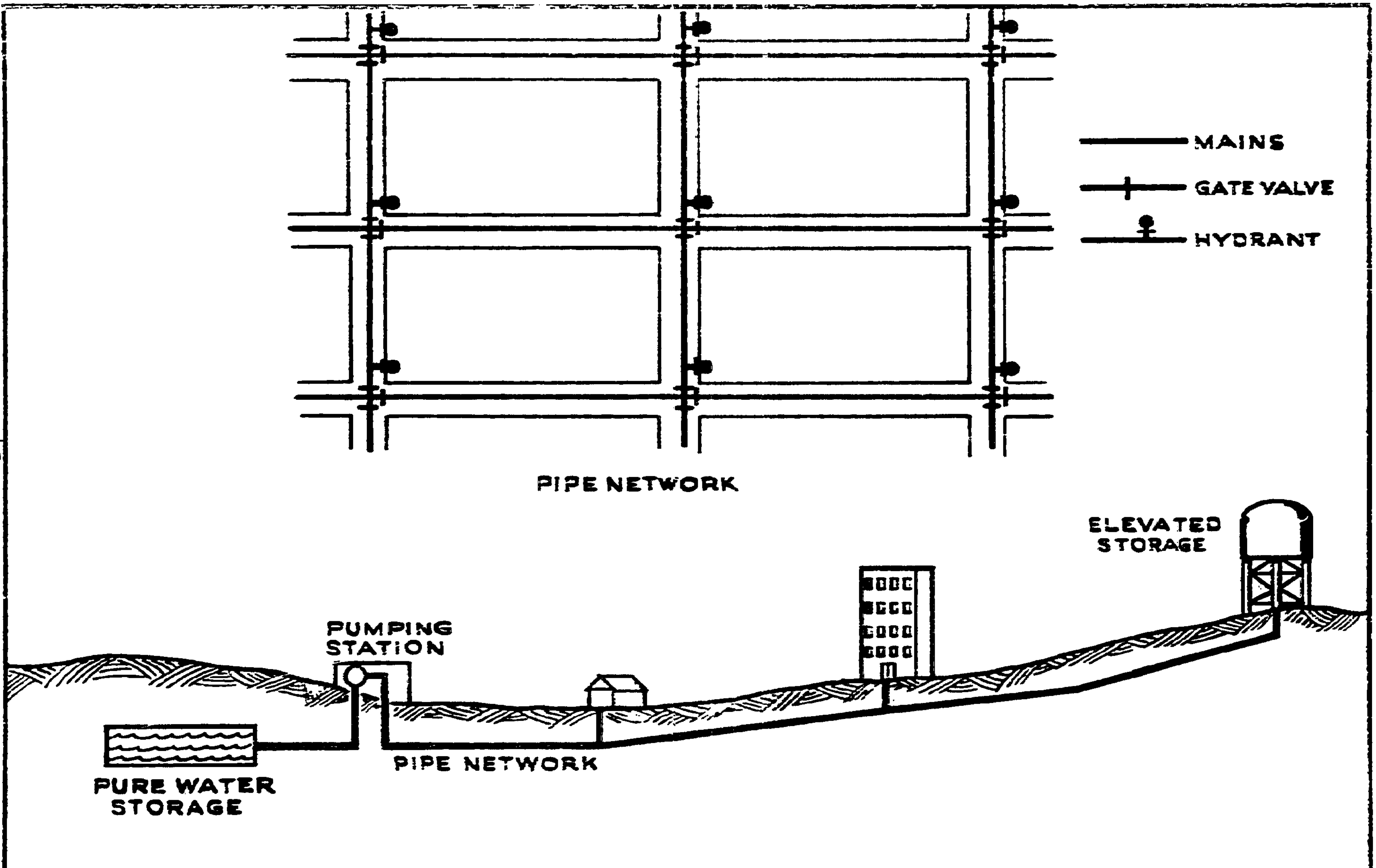
The fluorine content of water has an effect on teeth. Water containing over 1.5 ppm of fluorides has been found to cause fluorosis or mottled enamel in the teeth of persons drinking the water during the period from birth to 10 years old. On the other hand, a fluoride content of 1.0 ppm has been effective in reducing dental caries.

Fluorine may be added to water in the form of sodium floride by dry feed machines or in solution by aspirators or by hypochlorinators.

Beds of tricalcium phosphate, working on the ion exchange principal, are effective in reducing the fluoride content. Coagulation in conjunction with the lime-soda softening process will reduce the fluoride content to below 1 ppm in waters of high magnesium content.

C.5 WATER DISTRIBUTION SYSTEMS

The distribution system may be considered to extend from the discharge end of the treatment plant to the consumer. It consists of a piping system, storage facilities and, usually, pumping equipment (Figure C.24). Occasionally, a municipality may be located favorably with respect to a surface water supply and require no pumping. It is an exceptional system, however, that operates completely under gravity action.



STORAGE IN THE DISTRIBUTION SYSTEM

Pumps may be reciprocating or centrifugal, and may be driven by steam, gasoline or diesel engine or electric motor. Modern practice favors the electric motor-driven centrifugal pump. Gasoline and diesel engines are frequently used as standby emergency power where they may drive the pumps directly or serve as engine-generators. Reciprocating pumps and steam power are also used for special installations.

Storage is required in the distribution system to equalize pumping rates, to meet peak demands during the day, to meet fire demands and to provide water in the event of a breakdown. The reservoir may be underground, on the surface or elevated (Figure C.25).

Underground reservoirs are usually constructed of reinforced concrete and may be either circular or rectangular.

Reservoirs constructed essentially at grade elevation may be open or covered. A reservoir enclosed by earth embankments is typical of this type. The reservoir is usually lined with concrete, asphalt or masonry to reduce leakage. Circular or rectangular reinforced concrete and prestressed concrete tanks may also be used with or without covers. Steel standpipes are usually greater in height and serve the dual purpose of providing storage while maintaining pressure in the system. Elevated tank may be constructed of steel, concrete or wood; but steel is most common for larger tanks. Storage capacities up to 3 million gallons are common.

The piping system consists of a network designed to provide each consumer with the desired quantity of water at a suitable pressure. As previously mentioned, the short-term high demand for fire fighting generally establishes necessary sizes for many elements of the system. Cast iron, steel, concrete and asbestos cement are the types of pipe usually used in distribution systems. Valves located so as to permit portions of the system to be shut down for repairs are an important part

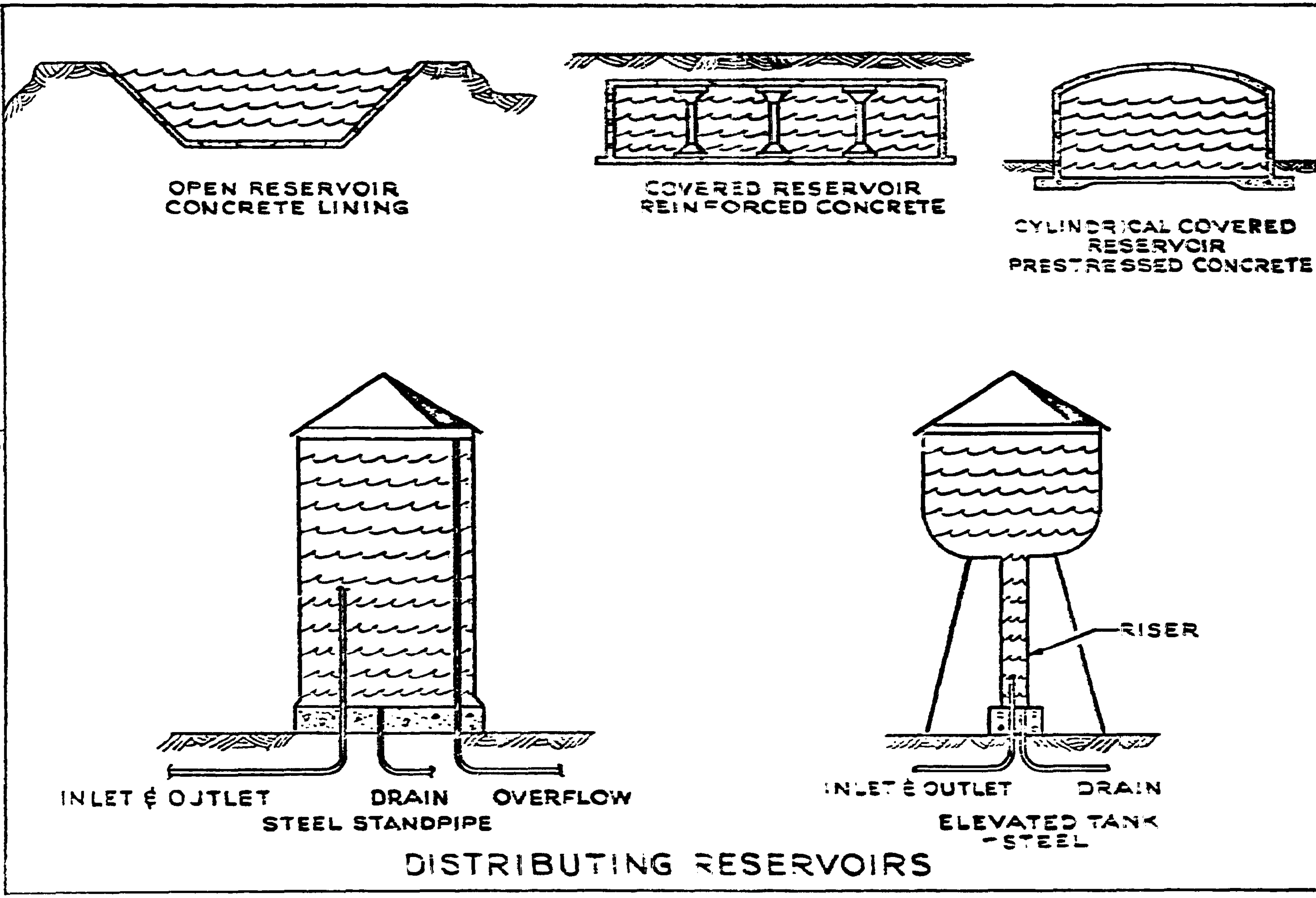

OPEN RESERVOIR
CONCRETE LINING
COVERED RESERVOIR
REINFORCED CONCRETE
CYLINDRICAL COVERED
RESERVOIR
PRESTRESSED CONCRETE
INLET & OUTLET
DRAIN
OVERFLOW
STEEL STANDPIPE
RISER
INLET & OUTLET
DRAIN
ELEVATED TANK
-STEEL
DISTRIBUTING RESERVOIRS

FIG. C.25

of the system. The location, type and capacity of fire hydrants are primarily determined by requirements of the National Board of Fire Underwriters, since insurance rates are based upon the adequacy of the water distribution system.

One type of service connection is indicated on Figure C.26, but many variations are possible. Valves properly located along the line permit routine maintenance and emergency repairs to be made without excessive loss of water or difficulty. Water meters serve to distribute the cost of water equitably and discourage waste. Check valves prevent backflow into the system and possible pollution of water in the mains.

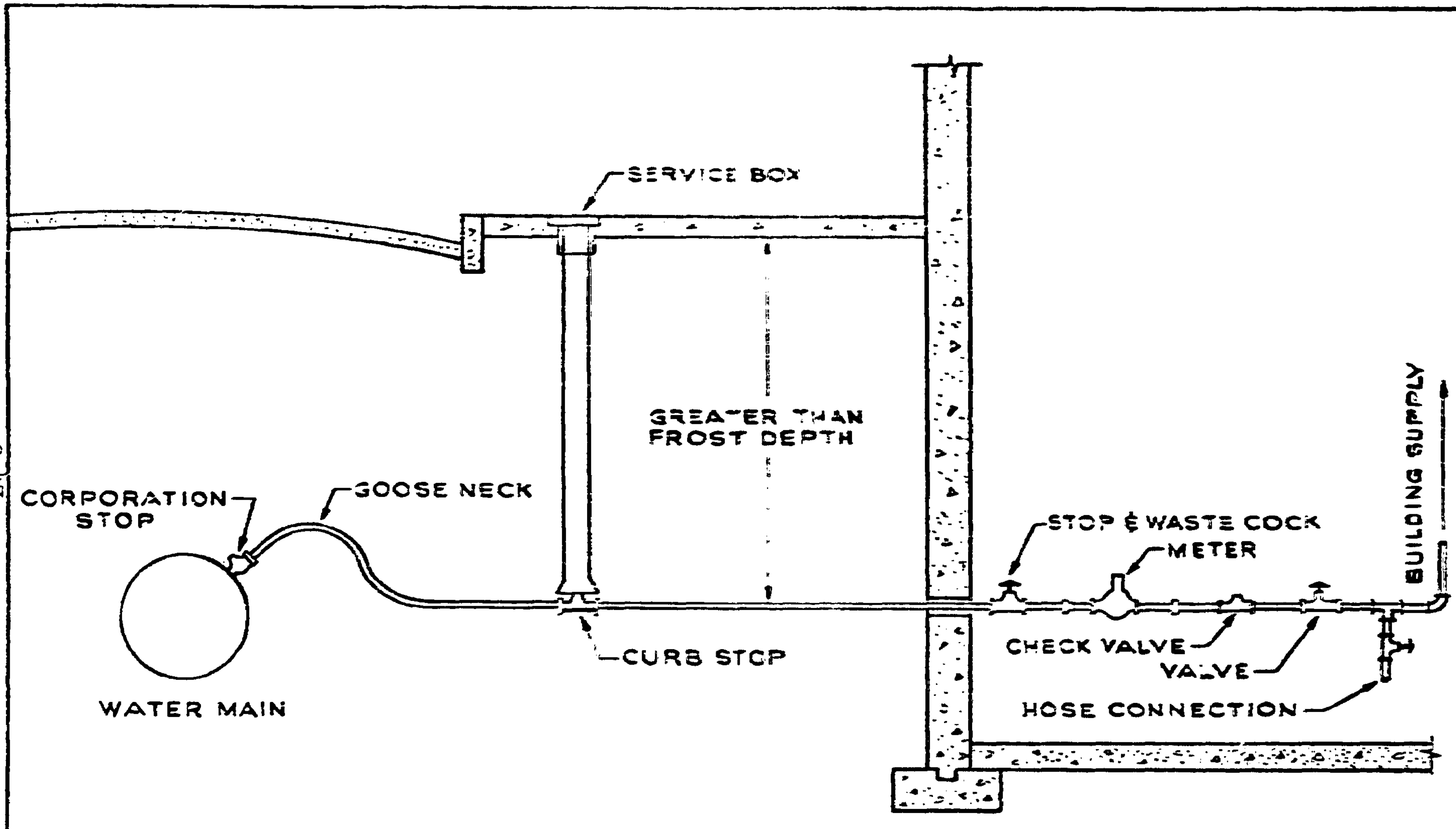
In many instances, pressure in the water main is not adequate to deliver water to the upper stories of multi-story buildings. In this case, pumps are often used in conjunction with storage tanks on the roof or at various levels in the building. Storage eliminates the need for continuous pumping and provides a supply of water for fire fighting. A siamese connection may be provided to permit a fire department pumper to augment the supply in emergencies. Figure C.27 is a illustration of a simple multi-story building water system.

C.6 CATEGORIES OF WATER SYSTEMS

Various authorities own or operate water systems. These may be political sub-divisions or private corporations. Generally, they fall into the following categories.

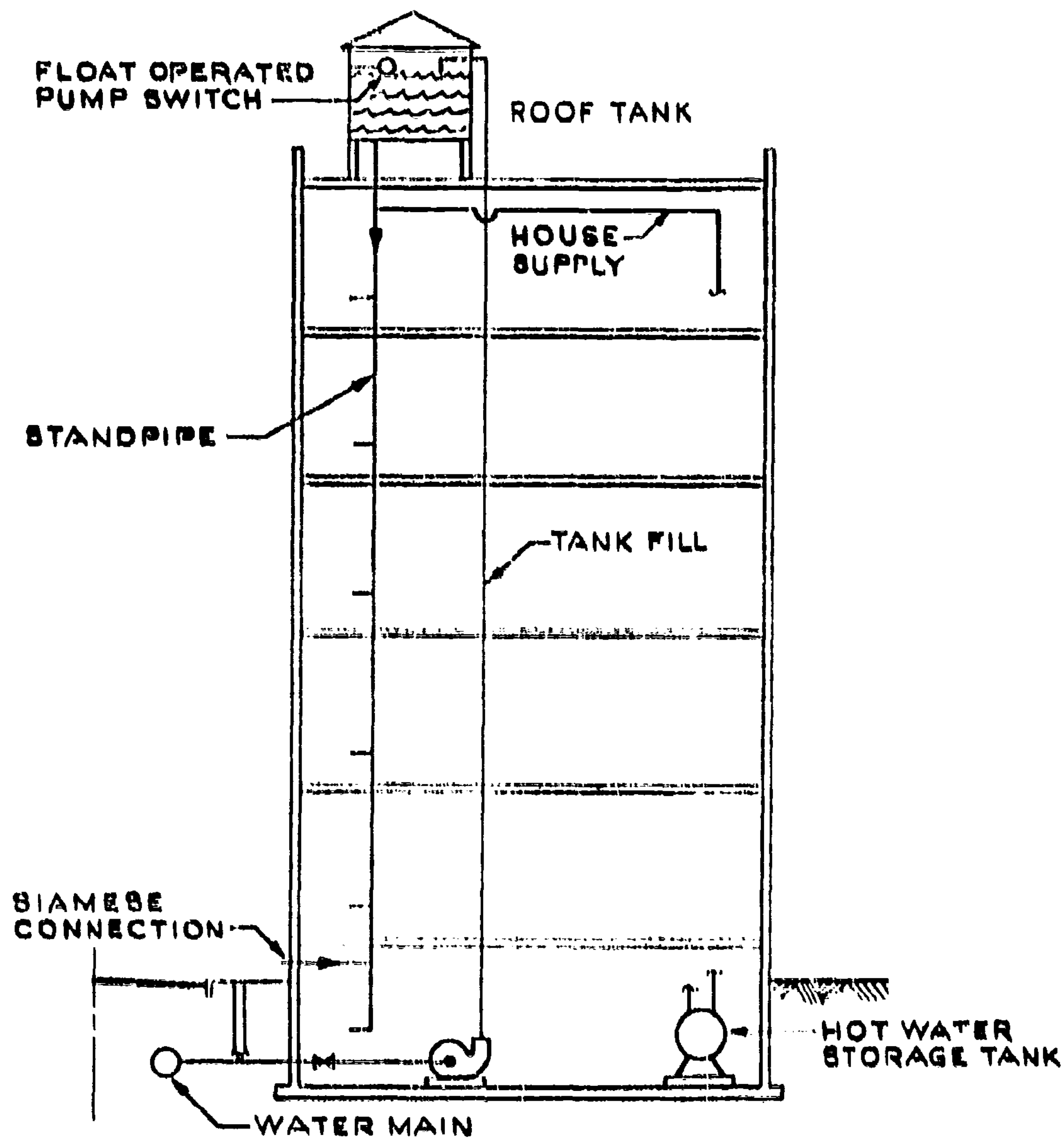
C.6.1 Water Authority

This is a public system, usually on a regional or multi-community basis with extensive area of operation. The probability of multi-type water sources is good, since this operation is generally composed of and interconnected with various smaller water systems.



SERVICE CONNECTION

F G. C.22



WATER SYSTEM
MULTI-STORY BUILDING

FIG. C.27

C.6.2 Municipal Systems

These are community owned; usually the sole water service of a community, and as such can establish total community service policy. In some instances, this type of system serves only a portion of the populace, sharing responsibility with a private water company or another authority.

An example is Rochester, New York, served by the City Water Department, Monroe County Water Authority and a private water company.

C.6.3 Private Water Company or Corporation

These are private, profit-making businesses that set their own policies regarding flexibilities, sources, etc., but are subject to State Public Utility Commissions as regards rates and quality of service. In certain areas of the country, these organizations serve many communities with the advantages of flexibility and interconnection with water authorities. There are, however, many small independent companies.

The role of the private water supplier has decreased over the years in favor of public systems. Approximately 15% of communities over 25,000 population are served by private water companies as compared with 85% by public systems.

C.6.4 Industrial Systems

These are self-supplied industrial systems rather than the public water system supply to industry discussed in section C.3. The systems vary greatly in regard to water quality and potability. Locations only generally coincide with that of public demand - that is, only insofar as availability of a labor market is a requirement of the industry. Distribution networks, similarly, have little relation to population or to public systems, except that some industries have emergency connections to municipal systems to avoid a possible shutdown of production. Normally, industrial supplies are less conservative than public supplies in that they have less tendency to have multiple sources.

One facet of interest is that many industrial systems have a high quality requirement as regards hardness and therefore often have ion exchange or other softening facilities, even though the public water supply system may have no such degree of treatment capability. This type of treatment, as discussed in section C.4.7, is superior in radioactive material removal to the types of treatment most commonly used for potable water supplies.

C.6.5 Private Supplies

These differ from the previous categories in that their purpose and concept is variable. The private supply in a low population rural area is most frequently a single dwelling domestic supply system - in most cases a ground water system. In metropolitan and some urban areas it is normally used for cooling water or some other special use where, for economical reasons or municipal system restrictions, it is desirable to have a private supply. Again these are normally well systems. These private supplies account for about 4% of the total water consumption of the country and number in the thousands, each of a fairly small capacity.