Environment Canada
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ENVIRO
Technical
Information for
Problem
Spills

CALCIUM CHLORIDE

May 1984

Canada

ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS REPORTS

The Environmental and Technical Information for Problem Spills (EnviroTIPS) manuals provide detailed information on chemical substances. This information is intended to assist the reader in designing countermeasures for spills and to assess their impact on the environment. This manual has been reviewed by the Technical Services Branch, Environmental Protection Service, and approved for publication. Approval does not necessarily signify that the contents reflect the views and policies of the Environmental Protection Service. Mention of trade names or commercial products does not constitute endorsement for use.

CALCIUM CHLORIDE

ENVIRONMENTAL AND TECHNICAL INFORMATION FOR PROBLEM SPILLS

Technical Services Branch
Environmental Protection Programs Directorate
Environmental Protection Service
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FOREWORD

The Environmental and Technical Information for Problem Spills (EnviroTIPS) manuals were initiated in 1981 to provide comprehensive information on chemicals that are spilled frequently in Canada. The manuals are intended to be used by spill specialists for designing countermeasures for spills and to assess their impact on the environment. The major focus of EnviroTIPS manuals is environmental. The manuals are not intended to be used by first-response personnel because of the length and technical content; a number of manuals intended for first-response use are available. The information in this manual was largely obtained from literature review. Efforts were made, both in compilation and in review, to ensure that the information is as correct as possible. Publication of these data does not signify that these data are recommended by the Government of Canada, nor any other group.

ACKNOWLEDGEMENTS

The final version of this manual was prepared by the staff of the Environmental Protection Service who rewrote the text, drafted illustrations and incorporated all comments and additions. The level of detail present was made possible by the many individuals, organizations and associations who provided technical data and comments throughout the compilation and subsequent review. The Canadian Chemical Producers' Association is especially acknowledged for its review and input to the manual. The draft of this manual was prepared under contract with Environment Canada by M.M. Dillon Consulting Engineers and Planners, Concord Scientific Corporation and Waterloo Engineering Limited.

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1 SUMMARY

CALCIUM CHLORIDE ($CaCl_2$ and $CaCl_2 \cdot 2H_2O$)

Water white to light yellow aqueous solution or white odourless solid (flakes, pellets or powder)

SYNONYMS

Calcium chloride, anhydrous; Calcium chloride dihydrate

IDENTIFICATION NUMBERS

UN No. No hazard no. required; CAS No. 10043-52-4 (anhydrous), 10035-04-8 (dihydrate); OHM-TADS No. 7216625; STCC No. No number required

GRADES & PURITIES

Solid forms:	dihydrate	- flake or powdered, 77 percent $CaCl_2$ in $CaCl_2 \cdot 2 H_2O$
	anhydrous	- flake or pellet, 94 to 97 percent $CaCl_2$
Liquid forms:	solution	- 32, 35, 38 percent (as $CaCl_2$ in water)
	liquor	- 40, 55 percent (as $CaCl_2$ in water)

IMMEDIATE CONCERNS

Fire: Not combustible

Human Health: Relatively nontoxic

Environment: Harmful to aquatic life at concentrations greater than 500 ppm

PHYSICAL PROPERTY DATA

	Anhydrous	Dihydrate	Solution
State (15°C, 1 atm):	solid	solid	liquid
Boiling Point:	1,935°C	176°C (dehydration)	116°C
Melting Point:	772°C	176°C (dehydration)	-7°C
Flammability:	not combustible	not combustible	not combustible
Specific Gravity (water = 1):	2.15	1.85	1.35 (25/4°C)
Solubility (in water)	very soluble	very soluble	very soluble
Behaviour (in water):	sinks and mixes	sinks and mixes	sinks and mixes
Odour Threshold:	odourles	odourless	odourless

ENVIRONMENTAL CONCERNS

Harmful to aquatic life and livestock in high concentrations. Calcium chloride does not bioaccumulate or have food chain contamination potential.

HUMAN HEALTH

Exposure Effects

Inhalation: Causes irritation of nose and throat

Contact: Contact with eyes, particularly by dust, causes irritation and possible transient corneal injury. Contact of solid with dry skin causes mild irritation; strong solutions cause marked irritation or burns

IMMEDIATE ACTION

Spill Control

Restrict access to spill site. Notify manufacturer. Stop the flow and contain spill, if safe to do so. Keep contaminated water from entering sewers or watercourses. Avoid contact with concentrated solutions.

Fire Control

Not combustible; most firefighting agents can be used on fires involving calcium chloride.

COUNTERMEASURES

Emergency Control Procedures in/on

Soil: Construct barriers to contain spill. Remove material by manual or mechanical means

Water: Contain by damming, water diversion or natural barriers

2 PHYSICAL AND CHEMICAL DATA

Physical State Properties

	Anhydrous	Dihydrate - $CaCl_2 \cdot 2H_2O$ (77 percent $CaCl_2$)	Solution (35 percent $CaCl_2$)
Appearance	Solid flakes or pellets, white (Dow 1974)	Solid flakes or powder, white (Dow ERIS 1979)	Water white to light yellow solution (Hooker MSDS 1972)
Usual shipping state(s)	Solid	Solid	Liquid (aqueous solution)
Physical state at 15°C, 1 atm	Solid	Solid	Liquid
Melting point	772°C (Kirk-Othmer 1978)	176°C (dehydration) (Kirk-Othmer 1978)	-
Freezing point	724°C (Ullmann 1975)		-7°C (Hooker PDS 1980; Dow 1974)
Boiling point	1,935°C (Kirk-Othmer 1978; Dow 1974) 1,670°C (Ullmann 1975)	175°C (dehydration) (Dow ERIS 1979)	116°C (Hooker MSDS 1972)

Densities

Specific gravity	2.15 (25°C/4°C) (CRC 1980)	1.85 (Kirk-Othmer 1978)	1.35 (Hooker PDS 1980)
Bulk density	1,024 kg/m^3 (Dow 1974)	881 kg/m^3 (Dow 1974)	1,355 kg/m^3 (Dow 1974)

Fire Properties

Flammability	Not combustible	Not combustible	Not combustible

Other Properties

Molecular weight of pure substance	110.99 (CRC 1980)	147.02 (CRC 1980)	
Constituent components of typical commercial grade	>94 percent $CaCl_2$ <5.0 percent NaCl <0.5 percent $MgCl_2$ (Ullmann 1975)	77-80 percent $CaCl_2$ 20-23 percent H_2O <2 percent NaCl <0.5 percent $MgCl_2$ (Ullmann 1975)	35-36 percent $CaCl_2$ (Hooker PDS 1980)

	Anhydrous	Dihydrate - $CaCl_2 \cdot 2H_2O$ (77 percent $CaCl_2$)	Solution: (35 percent $CaCl_2$)
Refractive index	1.52 (CRC 1980)		1.4301 (CRC 1980)
Viscosity			5.81 mPa·s (20°C) (CRC 1980)
Vapour pressure		0.37 kPa (40°C) (Dow 1974)	1.1 kPa (20°C) (Dow 1974)
Hygroscopicity	Absorbs 1.4 g H_2O/g $CaCl_2$) at 40 percent relative humidity (rH) and 17 g H_2O/g $CaCl_2$ at 95 percent rH (25°C) (Kirk-Othmer 1978)	Absorbs 1 g H_2O/g $CaCl_2 \cdot 2H_2O$ at 40 percent rH (25°C) (Kirk-Othmer 1978)	
Latent heat of fusion	25.5 kJ/mole (at melting point) (CRC 1980) 28.4 kJ/mole (m.p.) (Ullmann 1975; Kirk-Othmer 1978)	12.9 kJ/mole (at melting point) (Kirk-Othmer 1978)	
Latent heat of sublimation	324.3 kJ/mole (25°C) (Lange's Handbook 1979)		
Latent heat of vaporization	235.1 kJ/mole (25°C) (Lange's Handbook 1979) 226.1 kJ/mole (25°C) (Ullmann 1975)		
Heat of formation	-798.5 kJ/ mole (25°C) (JANAF 1971) -795.4 kJ/mole (25°C) (Ullmann 1975; Kirk-Othmer 1978)	-1,404 kJ/mole (Kirk-Othmer 1978)	
Ionization potential	10.2 eV (Rosenstock 1977)		
Heat of solution	-81.82 kJ/mole (Kirk-Othmer 1978)	176.4 kJ/(mole ·K) (25°C) (Kirk-Othmer 1978)	

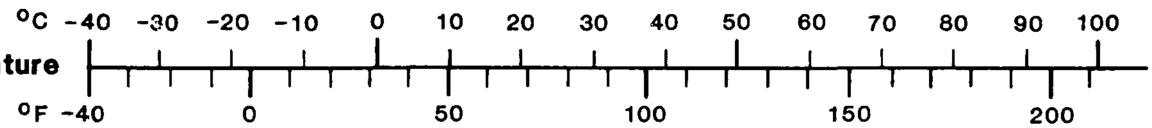
	Anhydrous	Dihydrate - $CaCl_2 \cdot 2H_2O$ (77 percent $CaCl_2$)	Solution (35 percent $CaCl_2$)
Heat of hydration	15.1 kJ/mole ($CaCl_2$ to $CaCl_2 \cdot H_2O$) (Ullmann 1975)	23.4 kJ/mole ($CaCl_2$ to $CaCl_2 \cdot 2H_2O$) (Ullmann 1975)	
Surface tension			93 mN/m (10°C) (Dow 1974)
Free entropy	-752.8 kJ/(mole •K) (Ullmann 1975)		
Standard entropy	123.1 kJ/(mole •K) (Ullmann 1975)		
Heat capacity constant pressure (Cp)	72.8 J/(mole·°C) (25°C) (JANAF 1971; Ullmann 1975) 74.4 J/(mole·K) (25°C) (Kirk-Othmer 1978)	176.4 J/(mole •K) (25°C) (Kirk-Othmer 1978)	
Coefficient of thermal expansion	6.7×10^{-5}/°C (20-190°C, cubic) (Ullmann 1975)		0.458×10^{-3}/°C (40% solution) (20°C) (Lange's Handbook 1979)
Thermal conductivity			0.55 $W \cdot m^{-1} \cdot s^{-1} \cdot {}^{\circ}C^{-1}$ (32°C) (30% solution) (Lange's Handbook 1979)
pH of aqueous solution			8.0 to 9.0 (Hooker PDS 1980)
Solubility			
In water	37.1 g/100 mL (0°C) 42.5 g/100 mL (20°C) (Ullmann 1975)	97.7 g/100 mL (0°C) (CRC 1980) 326 g/100 mL (60°C) (CRC 1980)	Very soluble (Dow 1974)
In other common materials	Soluble in ethanol, acetone and acetic acid (CRC 1980)	Ethanol: 50 g/100 mL (80°C) (CRC 1980)	

Structure

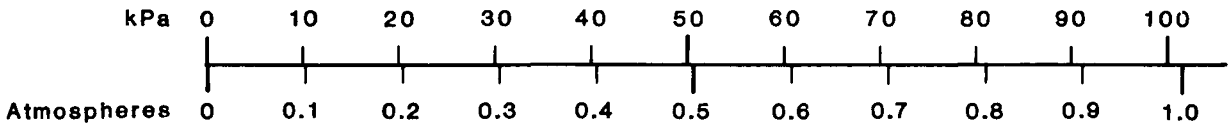
Calcium chloride is an extremely soluble solid which forms a number of stable hydrates. The properties of these hydrates are illustrated in Figure 1. The most common form of calcium chloride is the dihydrate ($CaCl_2 \cdot 2H_2O$). Other hydrates of importance are the monohydrate ($CaCl_2 \cdot H_2O$), the tetrahydrate ($CaCl_2 \cdot 4H_2O$) and the hexahydrate ($CaCl_2 \cdot 6H_2O$). All of the lower hydrates are very hygroscopic and absorb water readily from air to form the next stable hydrate, until the vapour pressure of the solution is in equilibrium with the water in the air.

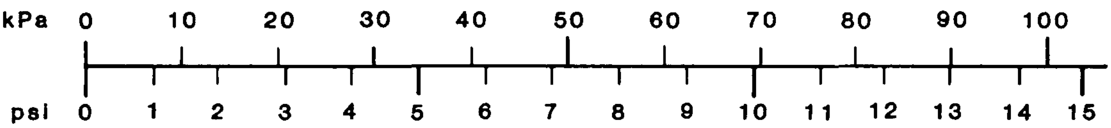
CONVERSION NOMOGRAMS

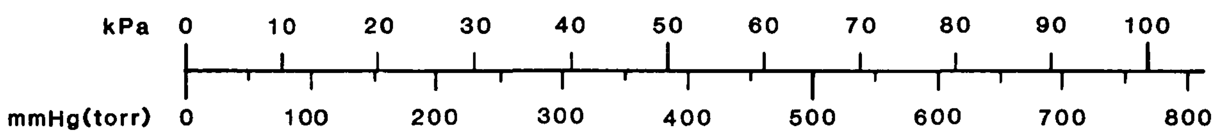
Temperature



Pressure 1 kPa = 1,000 Pa







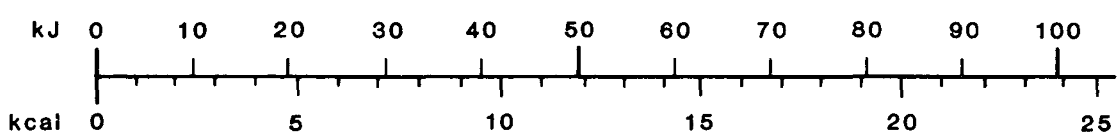
Viscosity

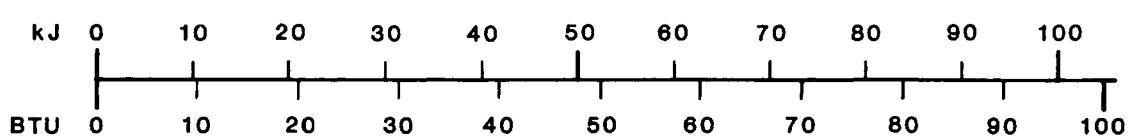
Dynamic 1 Pa·s = 1,000 centipoise (cP)

Kinematic 1 m^2/s = 1,000,000 centistokes (cSt)

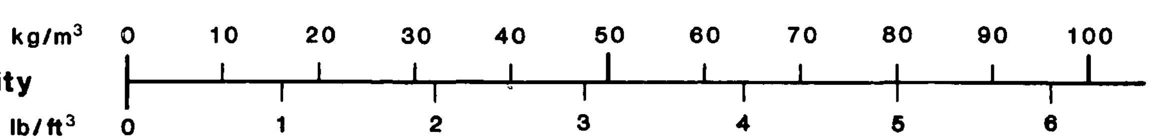
Concentration (in water)
1 ppm ≅ 1 mg/L

Energy (heat) 1 kJ = 1,000 J





Density



PHASE DIAGRAM FOR THE $CaCl_2 \cdot H_2O$ SYSTEM

Ref: DOW 1974, ULLMANN 1975, KIRK-OTHMER 1978

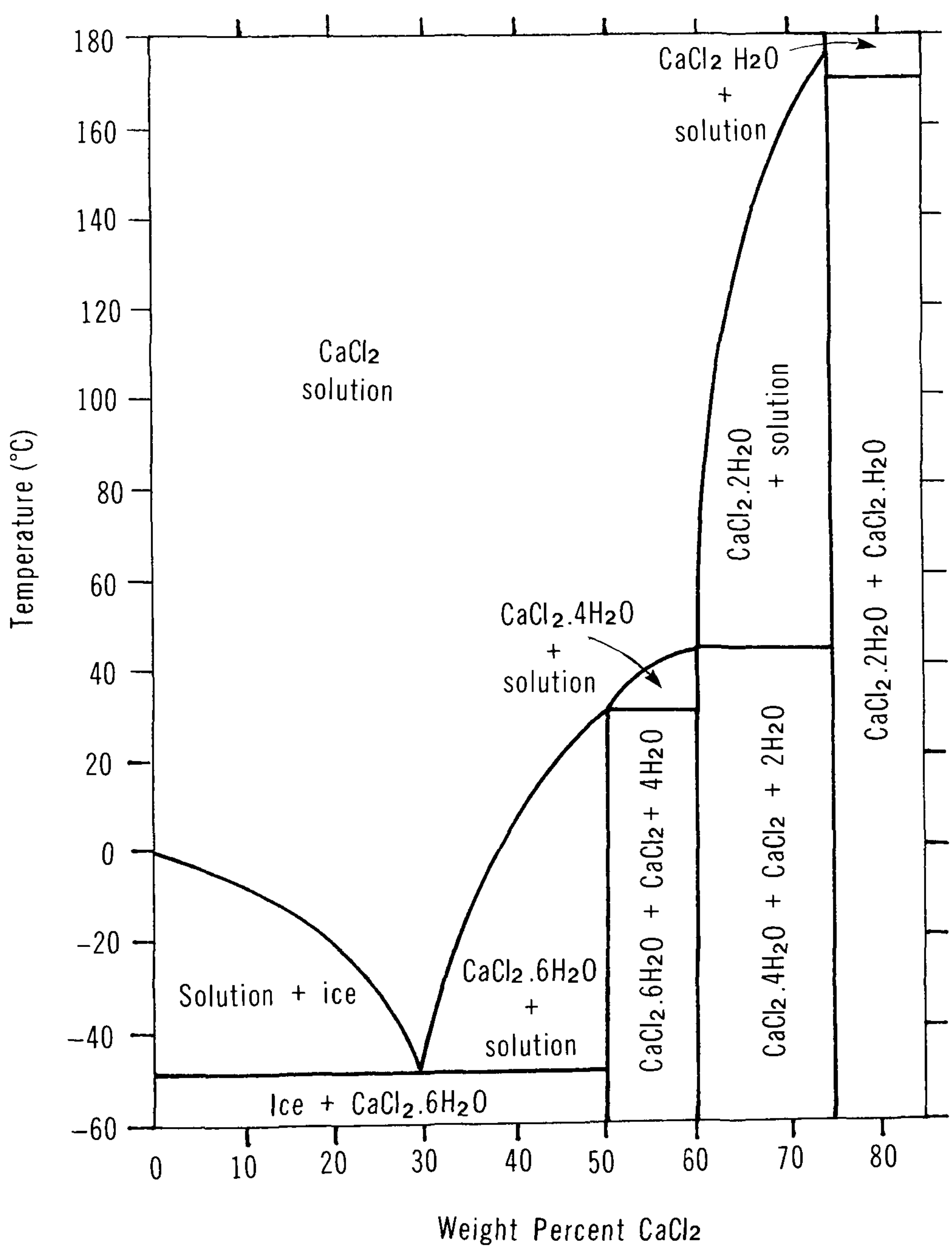


FIGURE 2

CALCIUM CHLORIDE (solutions)

DENSITY

Reference: DOW 1974

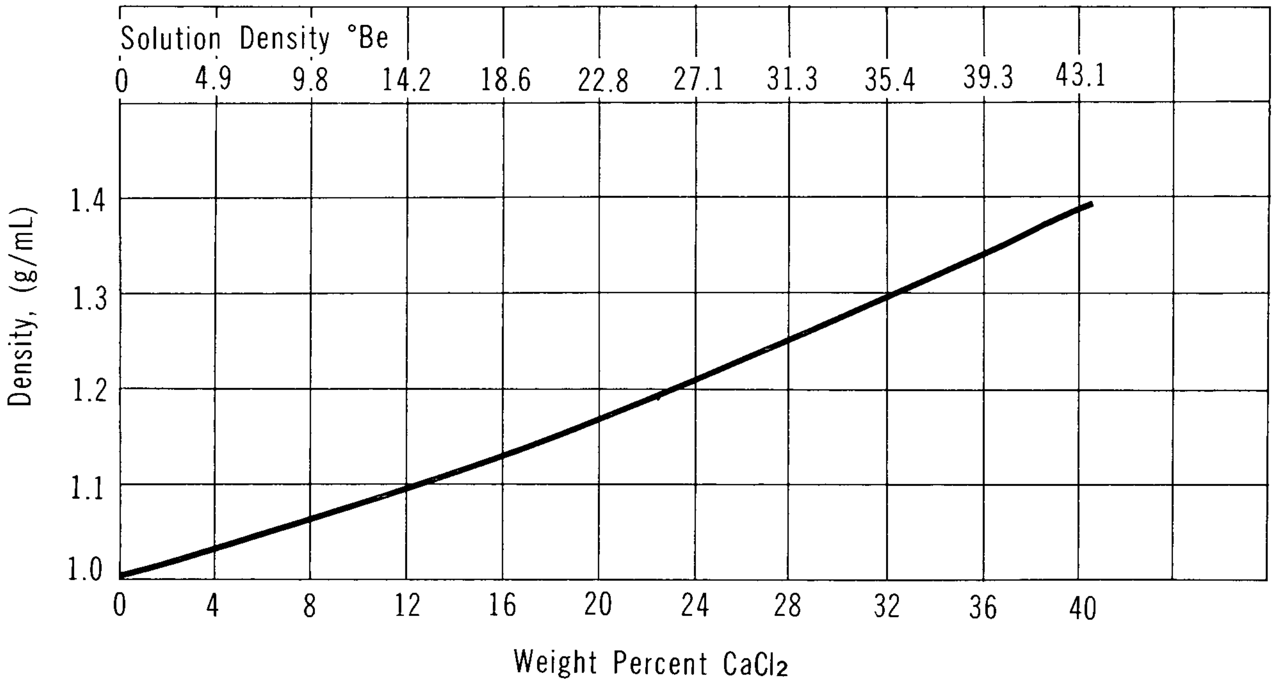


FIGURE 3

CALCIUM CHLORIDE (anhydrous)

SOLUBILITY IN WATER

Reference: ULLMANN 1975

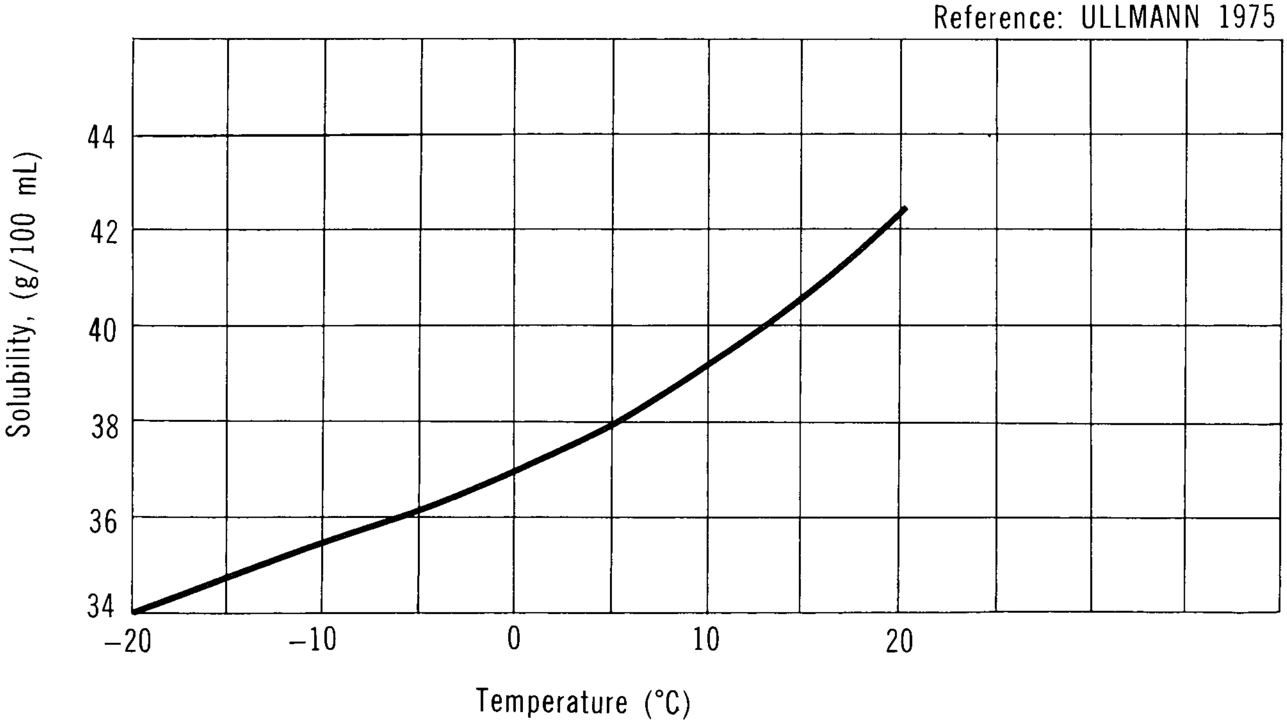


FIGURE 4

CALCIUM CHLORIDE (solutions and hydrates)

VAPOUR PRESSURE

Reference: DOW 1974

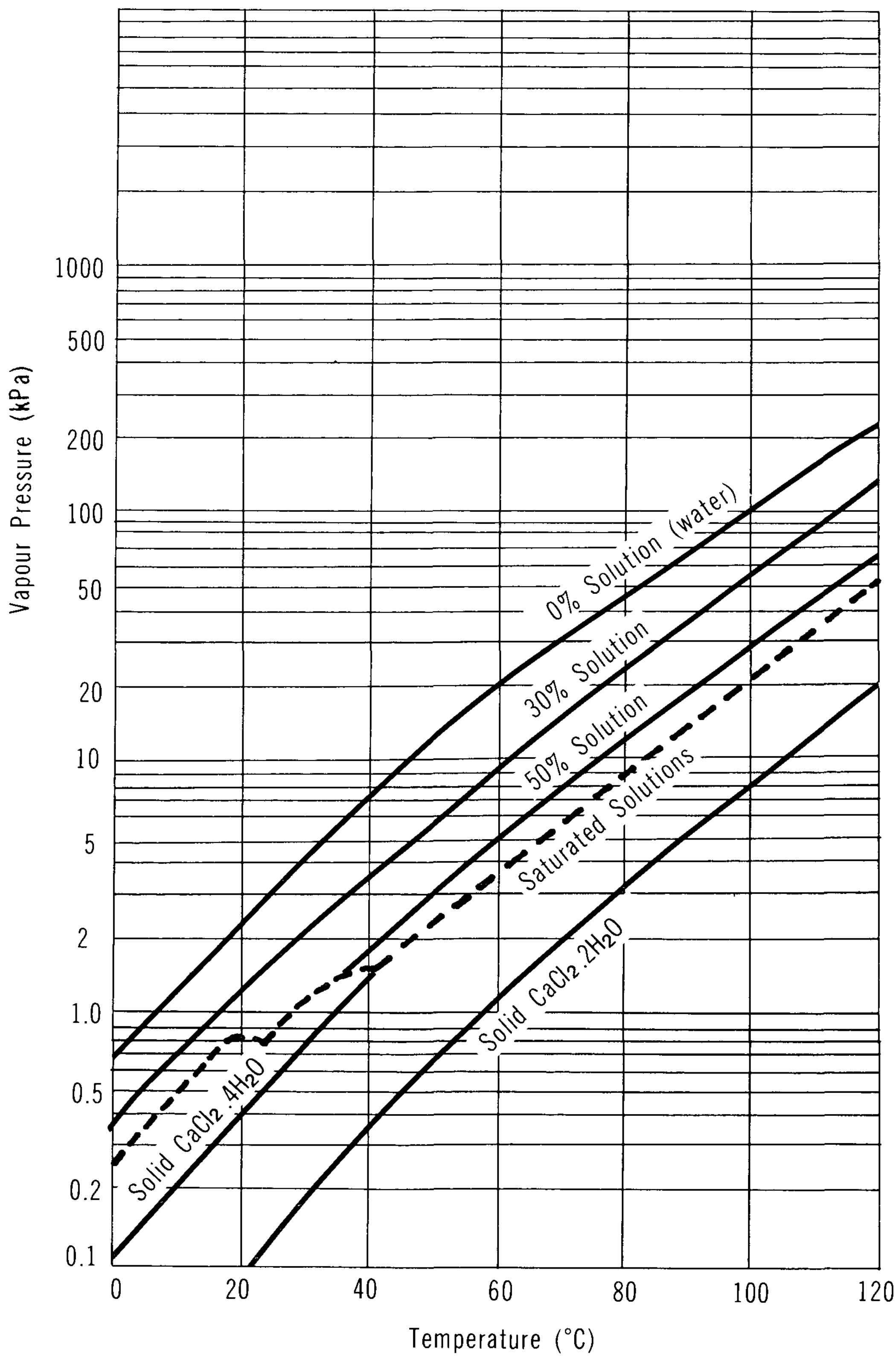


FIGURE 5

CALCIUM CHLORIDE (solutions)

VISCOSITY

Reference: DOW 1974

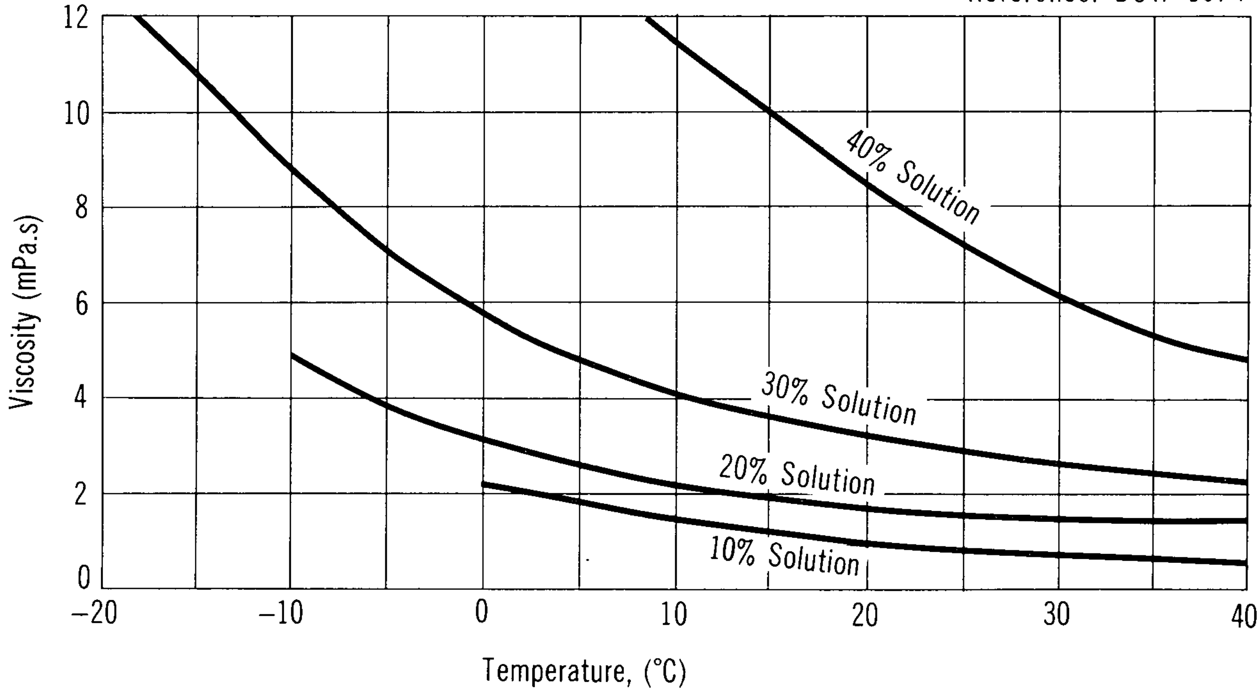
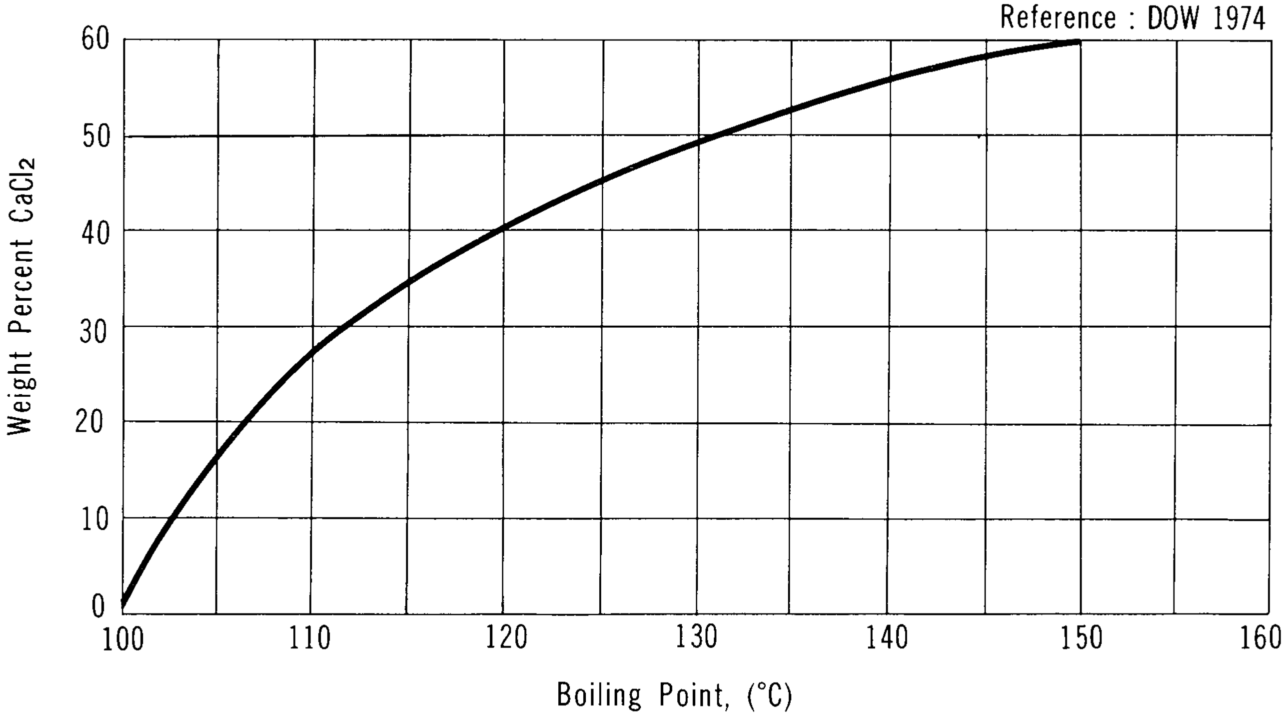


FIGURE 6

CALCIUM CHLORIDE (solutions)

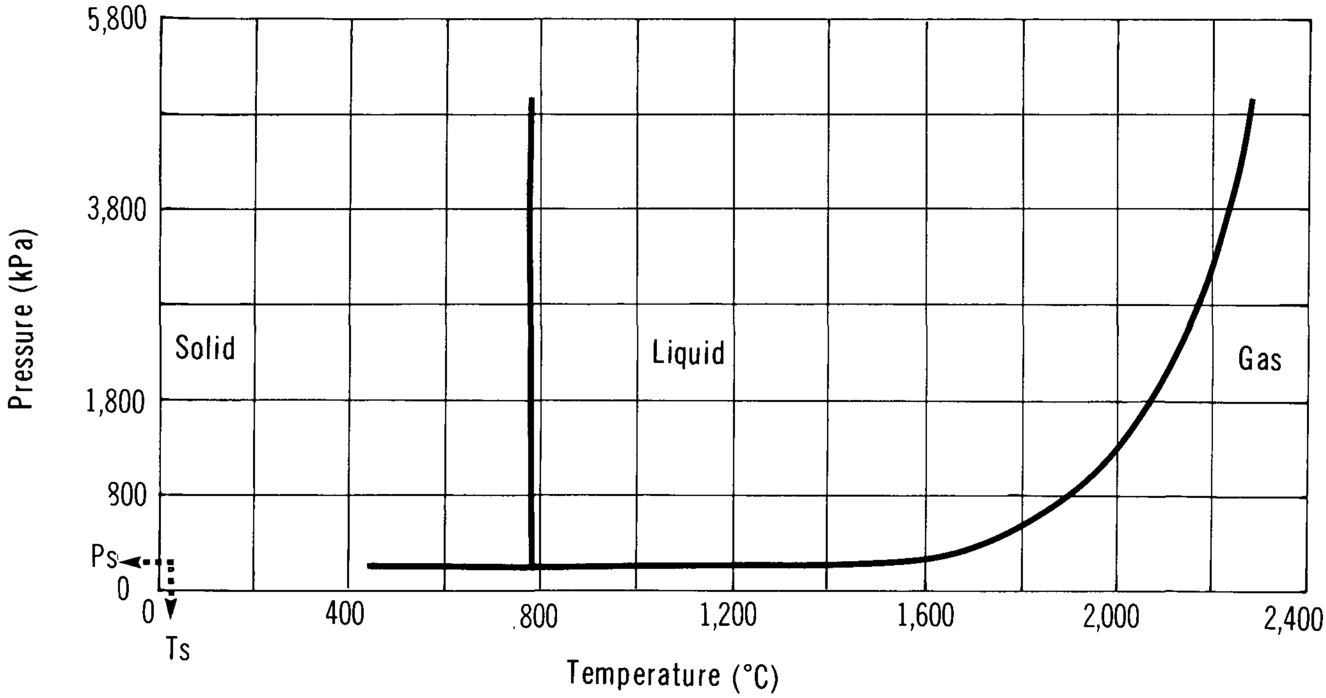
BOILING POINT

Reference : DOW 1974



CALCIUM CHLORIDE (anhydrous)

PHASE DIAGRAM



3 COMMERCE AND PRODUCTION

3.1 Grades, Purities (Dow 1974; Ullmann 1975; Kirk-Othmer 1978)

Calcium chloride is sold in four basic forms:

Form	Description	Purity
Flake or pellet	Anhydrous ($CaCl_2$)	94-97 percent
Flake or powdered (fines)	Dihydrate ($CaCl_2 \cdot 2H_2O$)	77-80 percent (as $CaCl_2$)
$CaCl_2$ in water	Solution	32, 35 and 38 percent (35 percent is the most common)
$CaCl_2$ in water	Liquor	40 and 55 percent

3.2 Domestic Manufacturers (CBG 1980; Corpus 1981)

Allied Chemical, Canada
201 City Centre Drive
Mississauga, Ontario
L5B 2T4
(416) 276-9211
Emergency (519) 252-5794

Dow Chemical Canada Inc.
P.O. Box 1012
Modeland Drive
Sarnia, Ontario
N7T 7K7
(519) 339-3131
(Imported from Midland or Ludington, Michigan, plants)

3.3 Major Transportation Routes

Current Canadian production of calcium chloride is located only in Ontario and Alberta. The largest production facility is in Amherstburg, near Windsor, Ontario, which accounts for 95 percent of the total production.

3.4 Production Levels (Corpus 1981; CCPA 1982)

Company, Plant Location		Nameplate Capacity kilotonnes/yr (1980)
Allied Chemical Canada, Amherstburg, Ont.		265
Allied Chemical Canada, Brooks, Alta.		5
Allied Chemical Canada, Drumheller, Alta.		5
	TOTAL	275
Domestic Shipments (1979)		114
Imports (1979)		9
	TOTAL SUPPLY	123

3.5 Manufacture of Calcium Chloride (Kirk-Othmer 1978; EPA 530/SW 104c)

3.5.1 General. Most of the calcium chloride (over 90 percent from Allied Chemical, Amherstburg, Ontario) is produced by the Solvay process as a co-product with soda ash (sodium carbonate). Calcium chloride is also obtained as a joint product of salt brine purification at the Alberta plants and this is the primary process in the USA.

3.5.2 Raw Materials. For the Solvay process, the primary reactants are limestone (calcium carbonate) and salt (sodium chloride). Salt brine is the raw material of the salt brine purification process.

3.5.3 Process.

3.5.3.1 Solvay process. The Solvay process is complex. The overall reaction is as follows:

$$CaCO_3 + 2NaCl \rightarrow Na_2CO_3 + CaCl_2$$

The individual reactions through the process include the following:

$$CaCO_3 \rightarrow CaO + CO_2$$
$$CaO + H_2O \rightarrow Ca(OH)_2$$
$$NaCl + CO_2 + NH_3 + H_2O \rightarrow NH_4Cl + NaHCO_3$$
$$2NaHCO_3 \rightarrow CO_2 + Na_2CO_3$$
$$Ca(OH_2) + 2NH_4Cl \rightarrow CaCl_2 + 2NH_3 + 2H_2O$$

These reactions are simplified; individual equations are not necessarily balanced but they provide an understandable overview.

3.5.3.2 Salt brine process. Magnesium chloride is removed from brine obtained from wells by concentration and crystallization or by treating with lime to precipitate magnesium hydroxide. Following this, the brine is concentrated in multiple effect evaporators to crystallize the sodium chloride. Finally, the brine is concentrated by heating and evaporation to produce $CaCl_2 \cdot 2H_2O$. This may be flaked for use as is or calcined to produce anhydrous $CaCl_2$.

3.6 Major Uses in Canada (Corpus 1981; Dow PS 1980; Hooker PDS 1980)

Calcium chloride is used for road building, road de-icing (snow and ice control), tire ballasting, oil well cementing, concrete mix additive, heat transfer brine, freeze-proofing of ores, coal or aggregates, and for waste treatment. In 1979, 79 percent of the product was sold for road building, base stabilization, and dust control.

3.7 **Major Buyers in Canada** (Corpus 1981; CBG 1981)

Arliss Chemicals, Pointe Claire, Quebec.
Anco Chemicals, Toronto, Ontario.
Anti-Hydro of Canada Company Sales, Montreal, Quebec.
BDH Chemicals, Toronto, Ontario.
Chemcor Corp., Montreal, Quebec.
CIL, Willowdale, Ontario.
Dow Chemical, Sarnia, Ontario.
Ford Motor, Windsor, Ontario.
W.R. Grace Canada, Toronto, Ontario.
Harrisons & Crosfield, Toronto, Ontario.
Lastoplex Chemicals, Weston, Ontario.
Mallinckrodt, Pointe Claire, Quebec.
Master Builders, Toronto, Ontario.
Miller Paving, Toronto, Ontario.
Municipal Works Departments.
Park Thermal, Georgetown, Ontario.
Pollard Bros., Harrow, Ontario.
Provincial Highway & Roads Departments
Record Chemical, Montreal, Quebec.
Shefford Chemicals, Granby, Quebec.
Sika Chemical Canada, Pointe Claire, Quebec.
Sternson, Brantford, Ontario.
Swift Canadian, Bramalea, Ontario.
Toronto Salt & Chemicals, Toronto, Ontario.
Travis Chemicals, Calgary, Alberta.
Van Waters & Rogers, Vancouver, B.C.
Winfield Chemical, Woodstock, N.B.

4 MATERIAL HANDLING AND COMPATIBILITY

4.1 Containers and Transportation Vessels

4.1.1 **Introduction** (Dow 1974; CCPA 1982). Calcium chloride is shipped in two basic forms, solid (anhydrous or dihydrate - the latter is more common) and liquid (solutions or liquor - a 35 percent solution is most common). The solid forms of the dihydrate ($CaCl_2 \cdot 2H_2O$) are the most common. The solid is shipped in bulk by rail and truck, in drums or bags by rail and truck, or also in bulk by ship. Solutions are transported in tank cars by rail or tank trucks.

4.1.2 **Bulk Shipment.** The hopper cars, used for bulk transport by rail, are usually AAR Class LO cars similar to bulk cement cars. Typical hopper cars are illustrated in Figure 8 and described in Table 2.

Railway tank cars used in the transportation of calcium chloride solutions and liquors are not regulated but CTC/DOT 111A tank cars may be used. Table 3 describes this specification. The most commonly used tank car is the 111A60W1, as illustrated in Figure 9 and described in Table 4.

Cars are equipped for unloading by pump, air, or gravity flow through a 102 to 152 mm (4-6 in.) diameter bottom outlet provided with an inner plug valve furnished with a steam jacket. In addition to bottom unloading, the cars may be unloaded from the top by compressed air. In this case, the calcium chloride is withdrawn through an eduction pipe which extends from the bottom of the tank to the top operating platform where it terminates with an unloading connection valve, usually a 51 mm (2 in.) threaded plug cock valve. Air pressure of 138 kPa (20 psi) is applied through the 25 mm (1 in.) air connection valve (CC 1958).

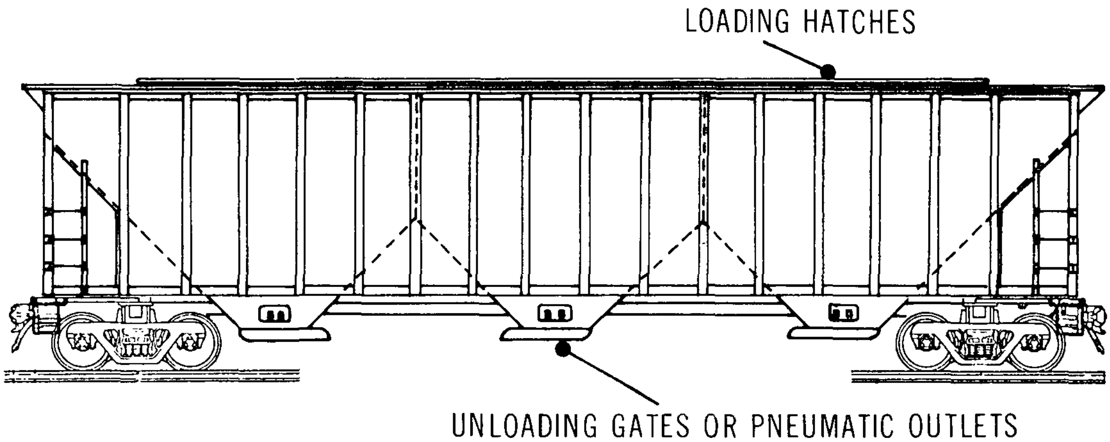
Materials of construction for the tank are dependent upon the grade of solution. For a 32 to 45 percent solution, a flange quality steel is required, usually ASTM A-283 Grade C steel plate with a 3 mm corrosion allowance. For liquors, 316 stainless steel or Monel alloys are most suitable. Tanks may be constructed of steel with an inner nickel liner; steel tanks may be lined with calcium chloride-resistant material (CC 1958).

Outside heating coils and glass wool insulation may be required for concentrated calcium chloride solutions. Constructed from 203 mm (8 in.) diameter type A53 Grade B steel pipe in half-oval form, the heating coils are laid out in a serpentine configuration across the bottom third of the tank (TCM 1979).

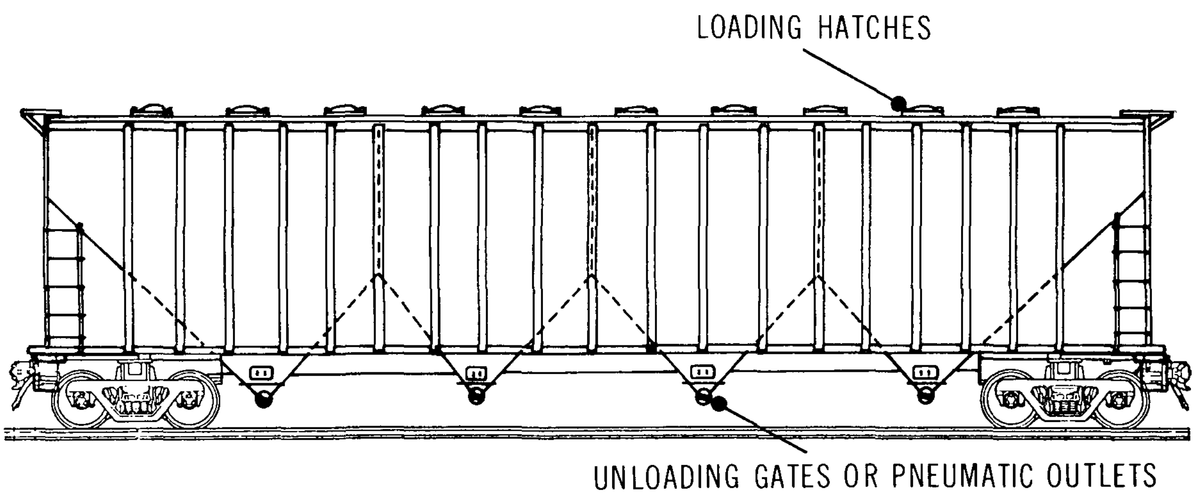
A safety relief valve set at 241 kPa (35 psi) is required on top of the rail car. The top unloading arrangement must be protected by a housing covering the air

COVERED HOPPER CARS - AAR CLASS LO

(Reference - CLC 1974, AAR 1983)



Typical 3 - Compartment Hopper Car



Typical 4 - Compartment Hopper Car

TABLE 2 TYPICAL RAILWAY HOPPER CAR SPECIFICATIONS - AAR CLASS LO (CLC 1974)

	Hopper Car Size (cu. ft.)	
Description	5,800	4,700
Overall		
Nominal capacity	164 m^3 (5,800 cu. ft.)	133 m^3 (4,700 cu. ft.)
Weight capacity	89,000 kg (196,000 lb.)	86,000 kg (190,000 lb.)
Car weight- empty	45,000 kg (100,000 lb.)	45,000 kg (100,000 lb.)
Car weight- (max.)	119,000 kg (263,000 lb.)	119,000 kg (263,000 lb.)
Hopper/Compartments		
Number	4	3
Material	Steel	Steel
Inside length (typical)	410 cm (160 in.)	460 cm (180 in.)
Inside width (typical)	300 cm (118 in.)	300 cm (118 in.)
Spacing between outlets	4 m (13 ft.)	5 m (15 ft.)
Slope angle	40-45°	40-45°
Approximate Dimensions		
Coupled length	21 m (68 ft.)	18 m (60 ft.)
Length over strikers	20 m (65 ft.)	17 m (57 ft.)
Length of truck centres	16 m (54 ft.)	14 m (46 ft.)
Clearance height	5 m (15 ft.)	5 m (15 ft.)
Height to top of running board	5 m (15 ft.)	4 m (14 ft.)
Overall width	3.1 m (123 in.)	3.2 m (126 in.)
Inside length	19 m (63 ft.)	17 m (55 ft.)

Loading/Unloading Fixtures

Loading Hatches: Cars typically equipped with 4 to 12 loading hatches. Typical dimensions of these are 36-61 cm (14-24 in.) in diameter or square dimensions.

Unloading Fixtures: Equipped with unloading gates at bottom of 36-61 cm (14-24 in.) square and/or pneumatic unloading connections 10-20 cm (4-8 in.) in diameter.

connection valve and the unloading connection valve. Solutions are never transported under pressure.

4.1.3 **Packaging.** Flake, powdered and pellet forms of calcium chloride are also transported in bags or drums (CC 1958; Dow 1974; CCPA 1982):

TABLE 3 RAILWAY TANK CAR SPECIFICATIONS

CTC/DOT* Specification Number	Description
111A60W1	Steel fusion-welded tank without dome. Uninsulated or insulated. 2% minimum outage. Gauging device. Test pressure 414 kPa (60 psi).
111A60F1	Steel forge-welded tank without dome. Uninsulated or insulated. 2% minimum outage. Gauging device. Test pressure 414 kPa (60 psi).
111A100W1	Steel fusion-welded tank without dome. Uninsulated or insulated. 2% minimum outage. Gauging device. Bottom outlet or washout optional. Test pressure 690 kPa (100 psi).

* Canadian Transport Commission and Department of Transportation (U.S.)

- multi-wall paper bags of 25 or 40 kg net weight (corresponding approximately to 60 and 90 lb. bags);
- steel drums of 45 or 181 kg (100 or 400 lb.) net weight of product. It should be noted that drums are rarely used.

4.2 Off-loading

4.2.1 Off-loading Equipment and Procedures for Railway Cars.

4.2.1.1 **Hopper cars.** Calcium chloride in flake or pellet form is unloaded from hopper cars into permanent storage bins or track hoppers below the track level or directly into conveyors. A belt conveyor, or less-commonly a screw conveyor, is used for removing calcium chloride from the bottom of track hopper installations (CC 1958; Dow 1974).

Prior to off-loading, certain precautions must be taken (CC 1958):

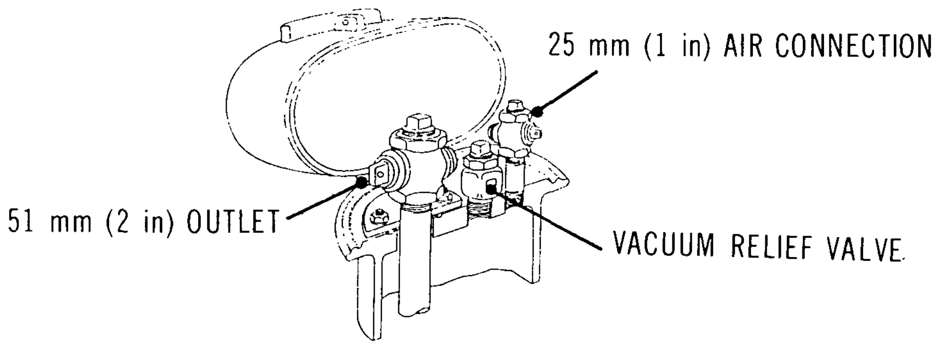
- The vented storage tank must be checked to make sure that it will hold the contents of the car.
- Personnel must not enter the car under any circumstances.
- Brakes must be set, wheels chocked and a derail employed.
- A safe operating platform must be provided at the unloading point.

4.2.2.2 **Tank cars.** Two means of off-loading are used for tank cars, top off-loading and bottom off-loading. Both means are shown in Figure 10.

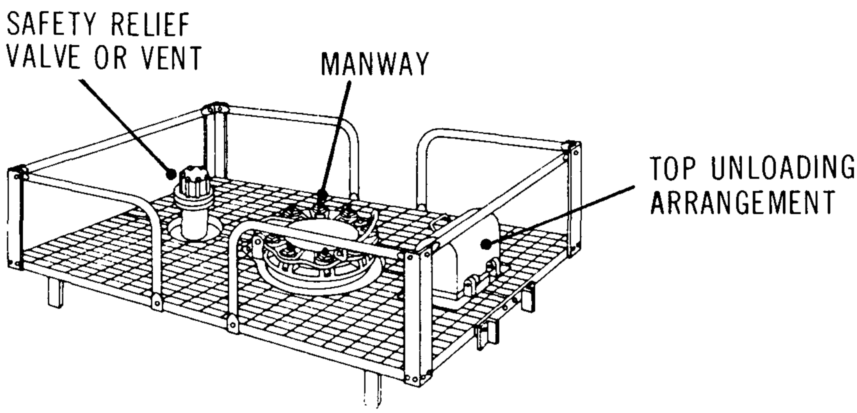
Proceed with top off-loading as follows (CC 1958):

RAILWAY TANK CAR - CLASS 111A60W1

(Reference - TCM 1979, RTDCR 1974)



Detail of top unloading arrangement



Detail of loading platform

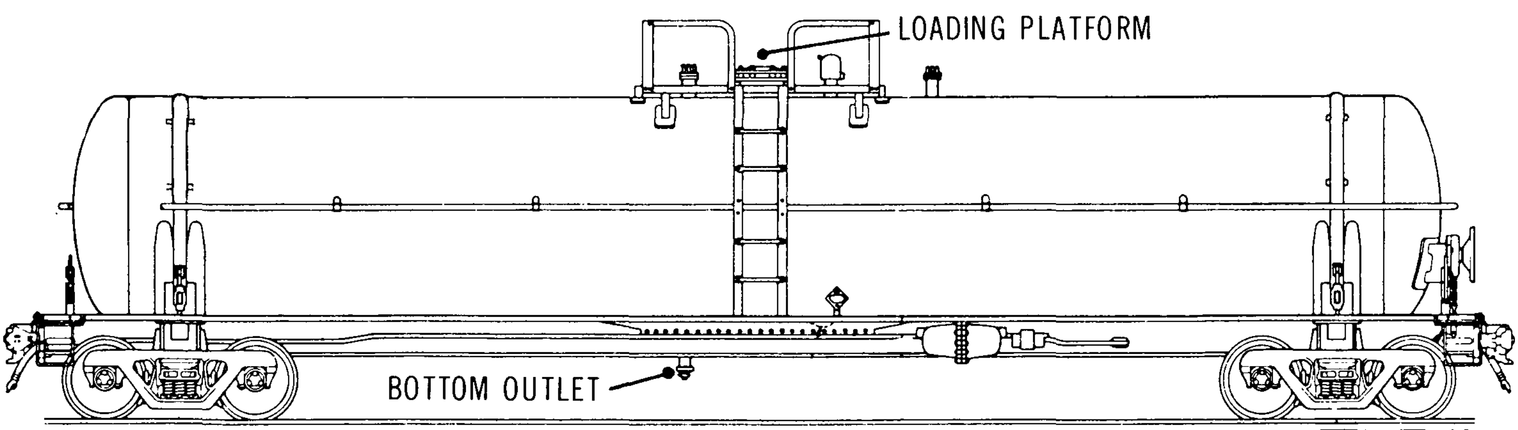
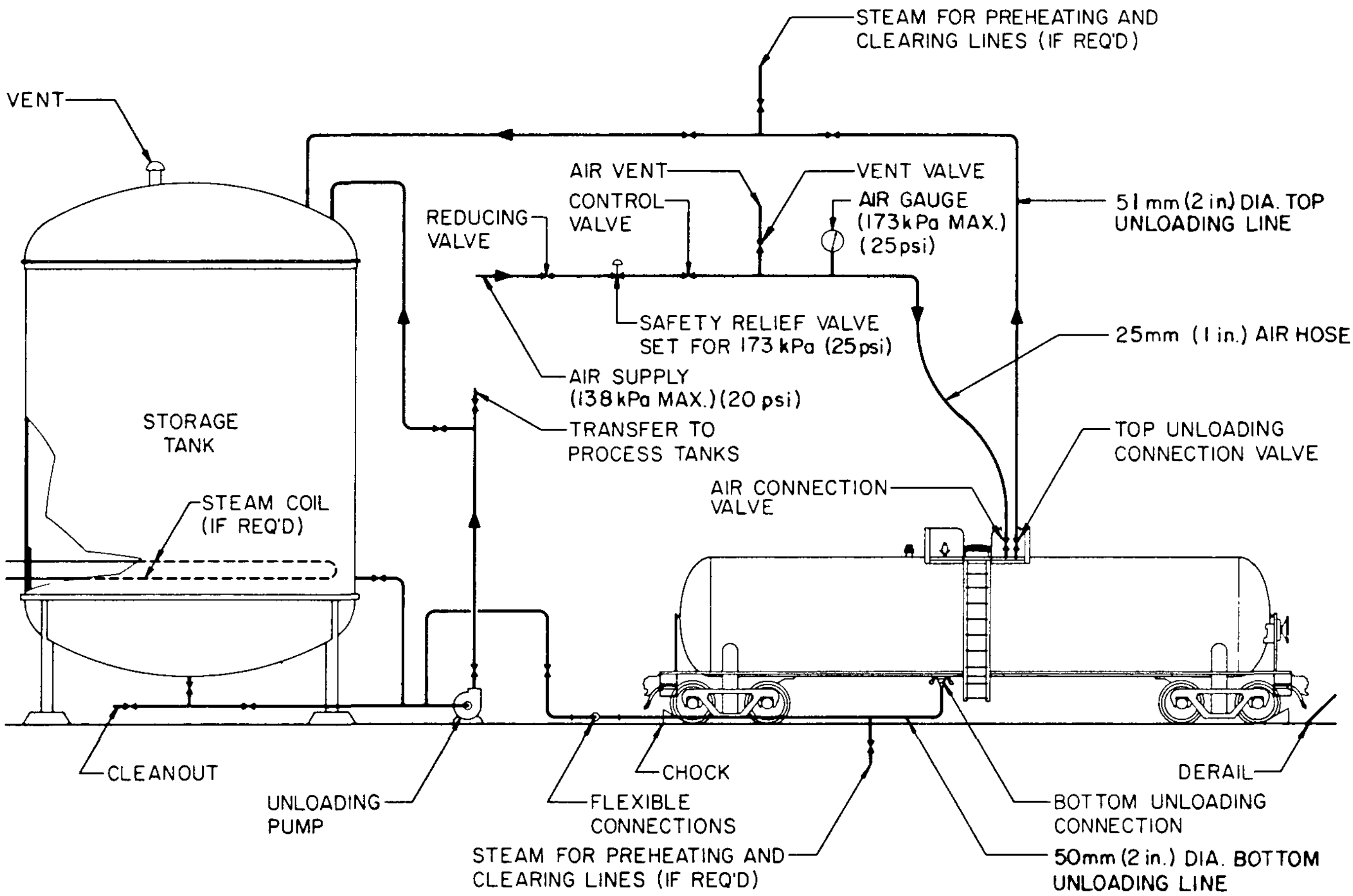


Illustration of tank car layout

TABLE 4 TYPICAL RAILWAY TANK CAR SPECIFICATIONS - CLASS 111A60W1 (TCM 1979; RTDCR 1974)

	Tank Car Size (Imp. gal.)					
Description	16,700		17,200		20,000	
<u>Overall</u>						
Nominal capacity	75,700 L (16,700 gal.)		78,000 L (17,200 gal.)		90,900 L (20,000 gal.)	
Car weight- empty	33,900 kg (74,700 lb.)		33,900 kg (74,700 lb.)		38,900 kg (85,800 lb.)	
Car weight- (max.)	119,000 kg (263,000 lb.)		83,500 kg (184,000 lb.)		119,000 kg (263,000 lb.)	
<u>Tank</u>						
Material	Steel		Steel		Steel	
Thickness	11.1 mm	(7/16 in.)	11.1 mm	(7/16 in.)	11.1 mm	(7/16 in.)
Inside diameter	2.60 m	(102 in.)	2.62 m	(103 in.)	2.74 m	(108 in.)
Test pressure	414 kPa	(60 psi)	414 kPa	(60 psi)	414 kPa	(60 psi)
Burst pressure	1,640 kPa	(240 psi)	1,640 kPa	(240 psi)	1,640 kPa	(240 psi)
<u>Approximate Dimensions</u>						
Coupled length	17 m	(57 ft.)	17 m	(57 ft.)	18 m	(60 ft.)
Length over strickers	16 m	(53 ft.)	16 m	(53 ft.)	17 m	(57 ft.)
Length of truck centres	13 m	(42 ft.)	13 m	(42 ft.)	14 m	(45 ft.)
Height to top of grating	4 m	(12 ft.)	4 m	(12 ft.)	4 m	(13 ft.)
Overall height	5 m	(15 ft.)	5 m	(15 ft.)	5 m	(15 ft.)
Overall width (over grabs)	3.2 m	(127 in.)	3.2 m	(127 in.)	3.2 m	(127 in.)
Length of grating	2-3 m	(8-10 ft.)	2-3 m	(8-10 ft.)	2-3 m	(8-10 ft.)
Width of grating	1.5-2 m	(5-6 ft.)	1.5-2 m	(5-6 ft.)	1.5-2 m	(5-6 ft.)
<u>Loading/Unloading Fixtures</u>						
<u>Top Unloading</u>						
Unloading connection	51 mm	(2 in.)	51 mm	(2 in.)	51 mm	(2 in.)
Manway/fill hole	203-356 mm	(8-14 in.)	203-356 mm	(8-14 in.)	203-356 mm	(8-14 in.)
Air connection	25-51 mm	(1-2 in.)	25-51 mm	(1-2 in.)	25-51 mm	(1-2 in.)
<u>Bottom unloading</u>						
Bottom outlet	102-152 mm	(4-6 in.)	102-152 mm	(4-6 in.)	102-152 mm	(4-6 in.)
<u>Safety Devices</u>	Safety vent or valve		Safety vent or valve		Safety vent or valve	
<u>Dome</u>	None		None		None	
<u>Insulation</u>	Optional		Optional		Optional	

TANK CAR UNLOADING



NOTE:

1 · FOR TOP OR BOTTOM UNLOADING METHOD SEE TEXT.

- After removing the protective housing from the air inlet and discharge line at the top of the car, connect the 51 mm (2 in.) unloading line to the discharge outlet and connect the 25 mm (1 in.) air line. Air pressure must be 138 kPa (20 psi) or less for unloading. A safety relief valve must be installed in the air line to release at 173 kPa (25 psi).
- After opening the air supply valve, the unloading connection valve can then be opened to unload the car.
- Once the car is empty, the air supply valve must be closed and the vent valve in the air line opened to allow the line pressure to equalize to atmospheric pressure.
- Reverse the above procedure to close up the car.

Proceed with bottom off-loading in the following manner using gravity flow, air, or pumping (CC 1958):

- In cold weather, apply steam to the bottom unloading connection. Steam coil connection valves (see Figure 10) should also be connected to live steam.
- After connecting the unloading line to the 152 mm (6 in.) bottom outlet, open the inside bottom valve by turning the valve rod handle at the top of the car.
- Off-load the car by gravity, air, or pump. When using air, the above-mentioned precautions must be observed.
- Reverse the above procedure to close up the car.

4.2.2 Off-loading Equipment for Bags and Drums. Equipment used for off-loading bags and drums previously described is similar to that used for handling dry goods in general and will be only briefly mentioned here. Most bagged products are moved on pallets and may or may not be strapped or stretch-wrapped for secure handling.

4.2.3 Specifications and Materials for Off-loading Equipment. The materials of construction for off-loading system components discussed in this section are listed below. The specifications of components of a typical off-loading system that will be discussed include pipes and fittings, flexible connections, valves, gaskets, pumps and storage tanks.

Schedule 40 seamless ASTM A106 carbon steel pipes and fittings are recommended. Flanged joints are preferable. All lines should be installed on a slight slope and without pockets. Outdoor lines may be traced and insulated (CC 1958).

Flexible steel hose, armoured rubber, or solid pipe with swivel joints may be used for the flexible sections of the unloading line.

For valving, lubricated iron plug cocks or all-iron gate valves will serve adequately. For hot solutions, lubricated nickel plug cocks will give best service (CC 1958). Asbestos gaskets or Viton can be used as a gasket material.

A single-suction centrifugal pump with Monel shaft and a nickel-iron shell and impeller is recommended for pumping. Back vanes on the impeller, an extra long stuffing box with a flowing water seal, and asbestos metallic packing will help reduce leakage (CC 1958). The pump should be equipped with flanges at both suction and discharge openings; screwed connections are subject to leakage and should be avoided.

Fusion-welded steel storage tanks of 56,750 L (12,500 gal.) and 75,700 L (16,700 gal.) capacity are commonly used. The storage tank should have heating coils to keep the liquid from freezing. The body and dished heads should be made of minimum 9 mm plate (CC 1958). The major consideration should be the specific gravity of calcium chloride solutions, since existing oil storage tanks are often used; thus, the head (or filling height) must be reduced (CCPA 1982).

4.3 Compatibility with Materials of Construction

The compatibility of calcium chloride with materials of construction is indicated in Table 5. The unbracketed abbreviations are described in Table 6. The rating system for this report is briefly described below.

Recommended: This material will perform satisfactorily in the given application.

Conditional: Material will show deterioration in the given application; however, it may be suitable for intermittent or short-term service.

Not Recommended: Material will be severely affected in this application and should not be used.

TABLE 5 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION

	Chemical		Material of Construction		
Application	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
1. Pipes and Fittings	Dilute	49	PE (DPPED 1967)		
	Dilute	60	PVC I, PVC II (DPPED 1967)		
	Dilute	71	ABS (DPPED 1967)		
	Saturated	79	PVDC (DCRG 1978)		
	Saturated	107	PP (DCRG 1978)		

TABLE 5 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

	Chemical		Material of Construction		
Application	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
1. Pipes and Fittings (cont'd)	Saturated	121	Chlorinated Polyether (DCRG 1978)		
	Saturated	135	PVDF (DCRG 1978)		
	Dilute	To operating limit of material	PVC I, ABS, PE (MWPP 1978) Iron		
			Nickel		
			Certain Nickel-Copper Alloys		
			Certain Nickel-Iron Alloys (CC 1958)		
2. Valves	10-30%	79	Brass or Bronze with Rings of Teflon or Graphite-Impregnated Asbestos (Dow 1974)	SS 316 (JSSV 1979)	Yellow Brass (Dow 1974)
3. Pumps	All	93	GRP with FPM "O" Ring		
			3% Nickel Iron (CC 1958) SS 316 (Dow 1974)	CI Shell and Rotor with Steel Shaft (CC 1958)	
	Concentrated	Hot	Nickel or Nickel Alloy (CC 1958)		
			All Iron Rotary Pumps		

TABLE 5 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical Conc.	Chemical Temp. (°C)	Material of Construction: Recommended	Conditional	Not Recommended
3. Pumps (cont'd)			Packing: Asbestos - Metallic (CC 1958)		
4. Storage	Most	Ambient	10 mm CS Plate of Flange Quality Steel (CC 1958)		Aluminum and its Alloys (Dow 1974)
	Most	Ambient	CS 3-10 mm (Dow 1974)		
5. Others	5%	20	SS 316 (ASS)	SS 302 SS 304 (ASS)	
	Satu-rated	20	SS 316 (ASS)	SS 302 SS 304 (ASS)	
			The following coatings may be used: - catalized epoxy - phenolic-epoxy copolymer - urethane - coal tar epoxy - vinyl (Dow 1974)		
	Diluted	40	uPVC, PE, PP POM, NR, NBR IIR, EPDM CR, FPM CSM (GF)		
	Diluted	60	PE, PP, POM NR, NBR, IIR EPDM, CR FPM, CSM (GF)	uPVC (GF)	
		60	PVC (TPS 1978)		
	Satu-rated	60	uPVC, PE, PP POM, NR, NBR IIR, EPDM, CR FPM, CSM (GF)		

TABLE 5 COMPATIBILITY WITH MATERIALS OF CONSTRUCTION (Cont'd)

Application	Chemical		Material of Construction		
	Conc.	Temp. (°C)	Recommended	Conditional	Not Recommended
5. Others (cont'd)		66	PP (TPS 1978)		
	Saturated	80	PP* NBR IIR, EPDM CR, FPM CSM (GF)	PE POM (GF)	uPVC NR (GF)
		82		PP (TPS 1978)	
		85	CPVC (TPS 1978)		
		121	PVDF (TPS 1978)		
	Saturated	100	NBR, CR, FMP CSM (GF)	PP, IIR, EPDM (GF)	uPVC, PE POM, NR (GF)
	All	Boiling	SS 316 (ASS)		SS 302 (ASS)
			NR, SBR, CR NBR, IIR, CSM Si, EPDM (GPP)		
	10 to 100%	24-100	Glass (CDS 1967)		
	10, 30, 50 or 100%	24			Concrete (CDS 1967)
	10 to 20%	24-100	Wood (Spruce, Maple) (CDS 1967)		
	100%	24	Wood (Spruce, Maple) (CDS 1967)		

* This material has been given a lower rating in a similar application by another reference.

TABLE 6 MATERIALS OF CONSTRUCTION

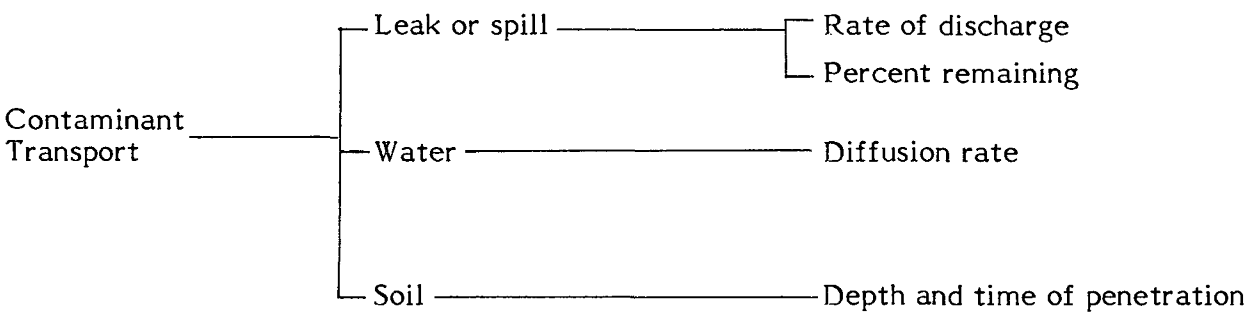
Abbreviation	Material of Construction
ABS	Acrylonitrile Butadiene Styrene
CI	Cast Iron, Austenitic
	Chlorinated Polyether
CPVC	Chlorinated Polyvinyl Chloride
CR	Polychloroprene (Neoprene)
CS	Carbon Steel
CSM	Chlorosulphonated Polyethylene (Hypalon)
	Concrete
EPDM	Ethylene Propylene Rubber
FPM	Fluorine Rubber (Viton)
GRP	Glass Reinforced Vinyl Ester
	Glass
	Iron
IIR	Isobutylene/Isoprene (Butyl) Rubber
NBR	Acrylonitrile/Butadiene (Nitrile, Buna N) Rubber
NR	Natural Rubber
	Nickel
	Nickel-Iron Alloy
	Nickel-Copper Alloy (Monel)
PE	Polyethylene
POM	Polyoxymethylene
PP	Polypropylene
PVC (followed by grade, if any)	Polyvinyl Chloride
PVDC	Polyvinylidene Chloride
PVDF	Polyvinylidene Fluoride
Si	Silicone
SBR	Styrene/Butadiene (GR-5, Buna S) Rubber
SS (Followed by Grade)	Stainless Steel
uPVC	Unplasticized Polyvinyl Chloride
	Wood (Spruce, Maple)

5 CONTAMINANT TRANSPORT

5.1 General Summary

Calcium chloride is transported as a solid or as an aqueous solution. When spilled in water, all forms will dissolve or mix rapidly. When spilled on soil, the liquid forms will spread on the surface and penetrate into the soil at a rate dependent on the soil type and its water content. Transport of calcium chloride toward the water table can be an environmental concern. Because calcium chloride is essentially nonvolatile, dispersion in air is not a problem and is not addressed below.

Factors to be considered for the transport of a calcium chloride spill in water and soil are shown below:



It is important to note that, because of the approximate nature of the contaminant transport calculations, the approach adopted throughout has been to use conservative estimates of critical parameters so that predictions are approaching worst case scenarios for each medium. However, the assumptions for each medium are consistent throughout the EnviroTIPS series, allowing comparison of the behaviours of different chemicals.

5.2 Leak Nomograms

5.2.1 Introduction. In aqueous form, calcium chloride is sometimes transported in railway tank cars. While the capacities of tank cars vary widely, one tank car has been chosen for development of the leak nomograms. It is approximately 2.75 m in diameter and 13.4 m long, with a carrying capacity of about 80,000 L. This size has been chosen consistently throughout the EnviroTIPS series to provide a basis of comparison. The aim of the nomograms is to provide a simple means to obtain the time history of the conditions in the tank car and the discharge rate of the liquid.

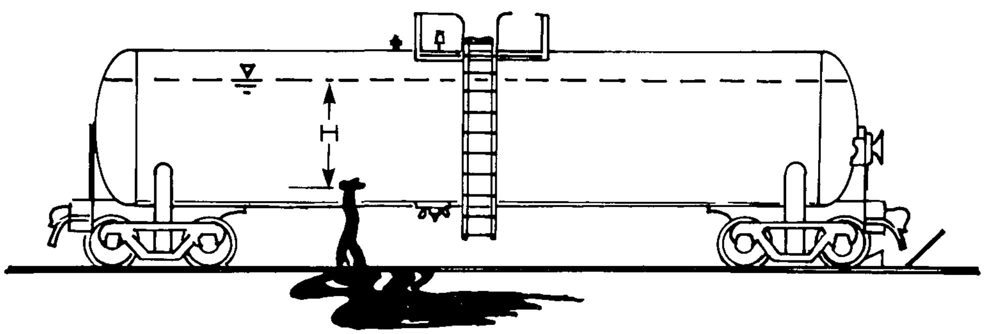


FIGURE 11 TANK CAR WITH PUNCTURE HOLE IN BOTTOM

5.2.2 Nomograms.

5.2.2.1 Figure 12: Percent remaining versus time. Figure 12 provides a means of estimating the percent of liquid remaining in the standard tank car after the time of puncture, for a number of different hole diameters. The hole diameter is actually an equivalent diameter and can be applied to a noncircular puncture.

The standard tank car (2.75 m ϕ x 13.4 m long) is assumed to be initially full (at t=0) with a volume of about 80,000 L of calcium chloride solution. The amount remaining at any time (t) is not only a function of the discharge rate over time, but also of the size and shape of the tank car.

5.2.2.2 Figure 13: Discharge rate versus time. Figure 13 provides a means of estimating the instantaneous discharge rate (L/s) at any time (t) after the time of puncture, for a number of equivalent hole diameters. The nomogram is only applicable to the standard tank car size with an initial volume of 80,000 L.

5.2.3 Sample Calculations.

i) Problem A

The standard tank car (2.75 m ϕ x 13.4 m long) filled with an aqueous solution of calcium chloride has been punctured on the bottom. The equivalent diameter of the hole is 150 mm. What percent of the initial 80,000 L remains after 10 minutes?

FIGURE 12

CALCIUM CHLORIDE

PERCENT REMAINING VS TIME

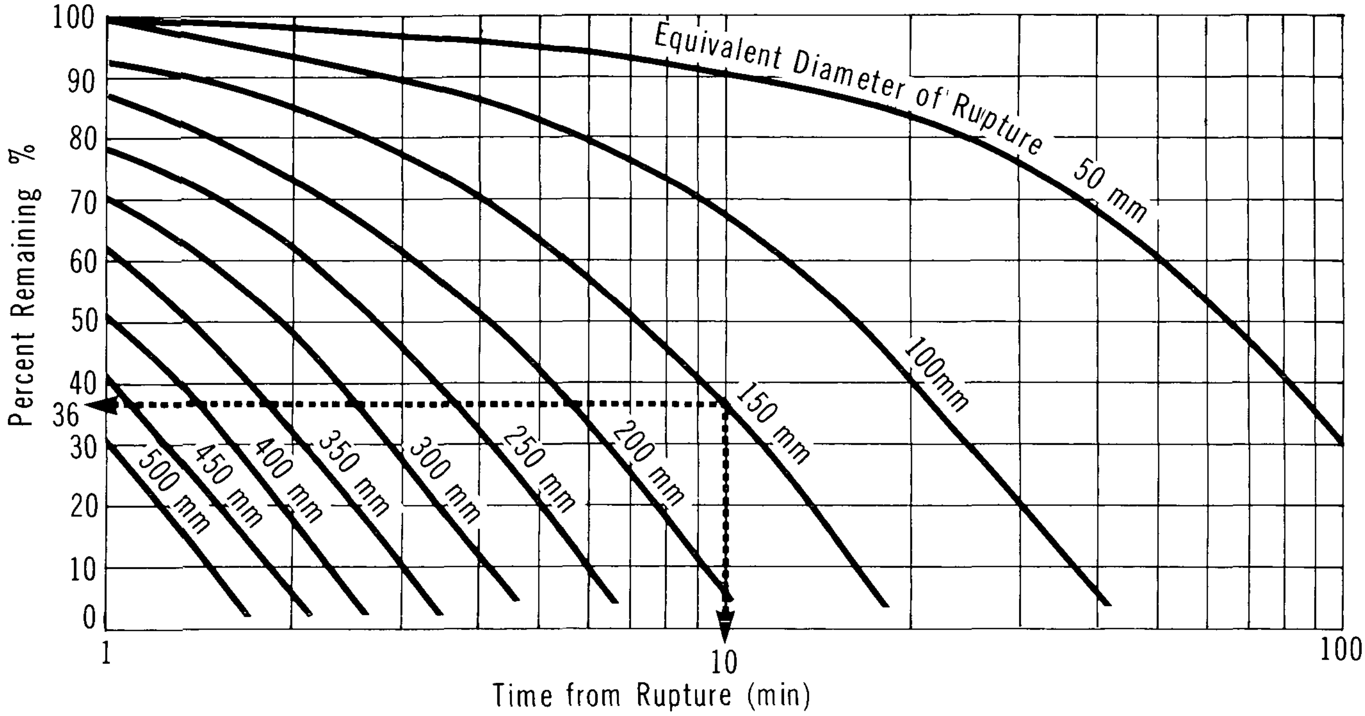
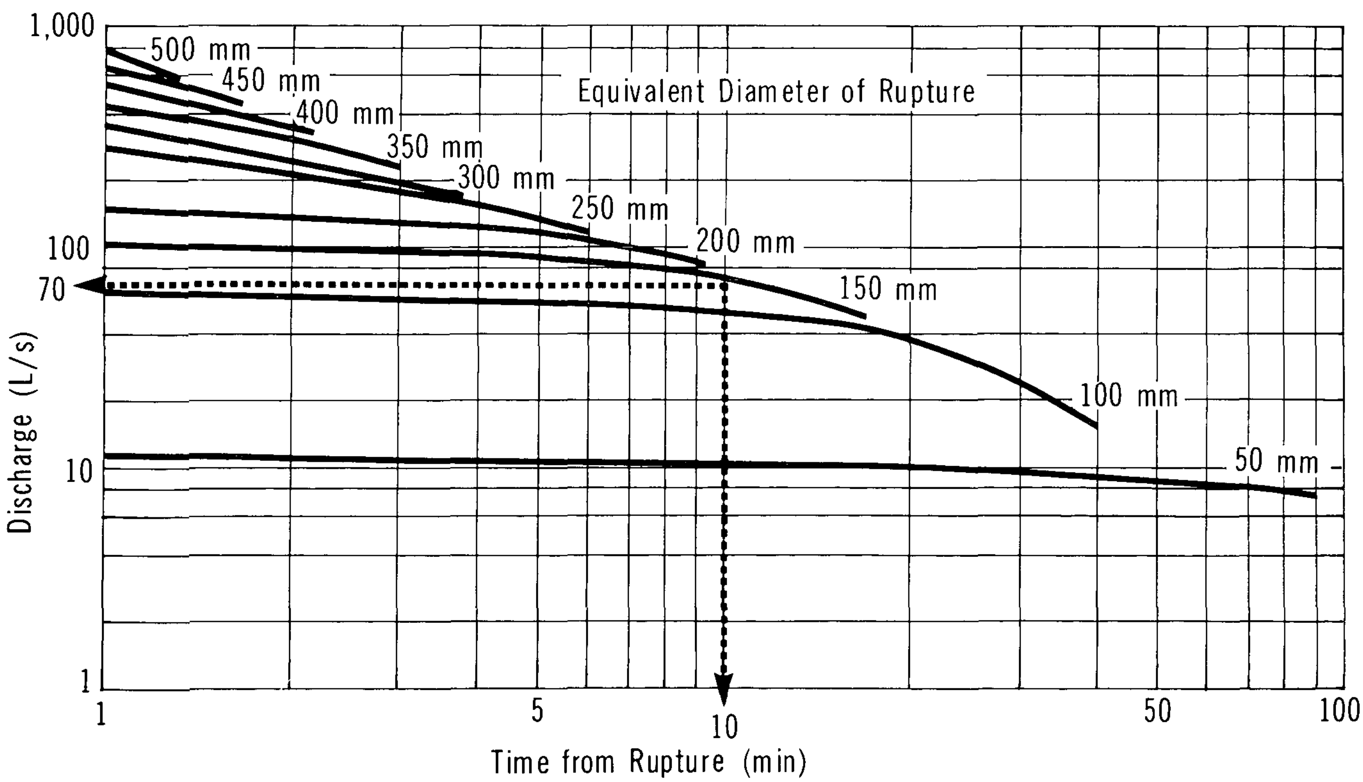


FIGURE 13

CALCIUM CHLORIDE

DISCHARGE RATE VS TIME



Solution to Problem A

- Use Figure 12
- With t=10 min and d=150 mm, the amount remaining is about 36 percent or 28,800 L

ii) Problem B

With the same conditions as Problem A, what is the instantaneous discharge rate from the tank 10 minutes after the accident?

Solution to Problem B

- Use Figure 13
- With t=10 min and d=150 mm, the instantaneous discharge rate (q) = 70 L/s

5.3 Dispersion in the Air

Because calcium chloride is nonvolatile in foreseeable spill circumstances, there is no significant potential for dispersion in air.

5.4 Behaviour in Water

5.4.1 Introduction. When spilled on a water surface, calcium chloride will dissolve rapidly. Mixing takes place and the spill is diluted. This mixing can generally be described by classical diffusion equations with one or more diffusion coefficients. In rivers, the principal mixing agent is stream turbulence, while in calm water mixing takes place by molecular diffusion.

To estimate the pollutant concentration in a river downstream from a spill, the turbulent diffusion has been modelled. The model employed is strictly applicable to neutrally buoyant liquids and solids that dissolve in water. As calcium chloride is denser than water, the maximum concentration would be expected near the bottom.

The one-dimensional model uses an idealized rectangular channel section and assumes a uniform concentration of the pollutant throughout the section. Obviously, this applies only to points sufficiently far downstream of the spill where mixing and dilution have distributed the pollutant across the entire river channel. The model is applicable to rivers where the ratio of width to depth is less than 100 ($W/d < 100$) and assumes a Manning's roughness coefficient of 0.03. Details of the model are outlined in the Introduction Manual.

No modelling has been carried out for molecular diffusion in still water. Rather, nomograms have been prepared to define the hazard zone and the average concentration within the hazard zone as a function of spill size, but independent of time.

5.4.2 **Nomograms.** The following nomograms are presented to calculate pollutant concentrations in non-tidal rivers and in lakes (still water).

Non-tidal Rivers

Figure 15: time versus distance for a range of average stream velocities

Figure 16: hydraulic radius versus channel width for a range of stream depths

Figure 17: diffusion coefficient versus hydraulic radius for a range of average stream velocities

Figure 18: alpha* versus diffusion coefficient for various time intervals

Figure 19: alpha versus delta* for a range of spill sizes

Figure 20: maximum concentration versus delta for a range of river cross-sectional areas

Lakes or Still Water Bodies

Figure 21: volume versus radius for the hazard zone for a range of lake depths

Figure 22: average concentration versus volume for the hazard zone for a range of spill sizes

The flow chart in Figure 14 outlines the steps required to estimate downstream concentration after a spill and identifies the nomograms to be used. These nomograms (Figures 15 through 20) are described in the following sub-sections.

5.4.2.1 Nomograms for non-tidal river.

Figure 15: Time versus distance. Figure 15 presents a simple relationship between average stream velocity, time, and distance. Using an estimate of average stream velocity (U), the time (t) to reach any point of interest, at some distance (X) downstream of the spill, can be readily obtained from Figure 15.

Figure 16: Hydraulic radius versus channel width. The model used to estimate downstream pollutant concentrations is based on an idealized rectangular channel of width (W) and depth (d). The hydraulic radius (r) for the channel is required in order to estimate

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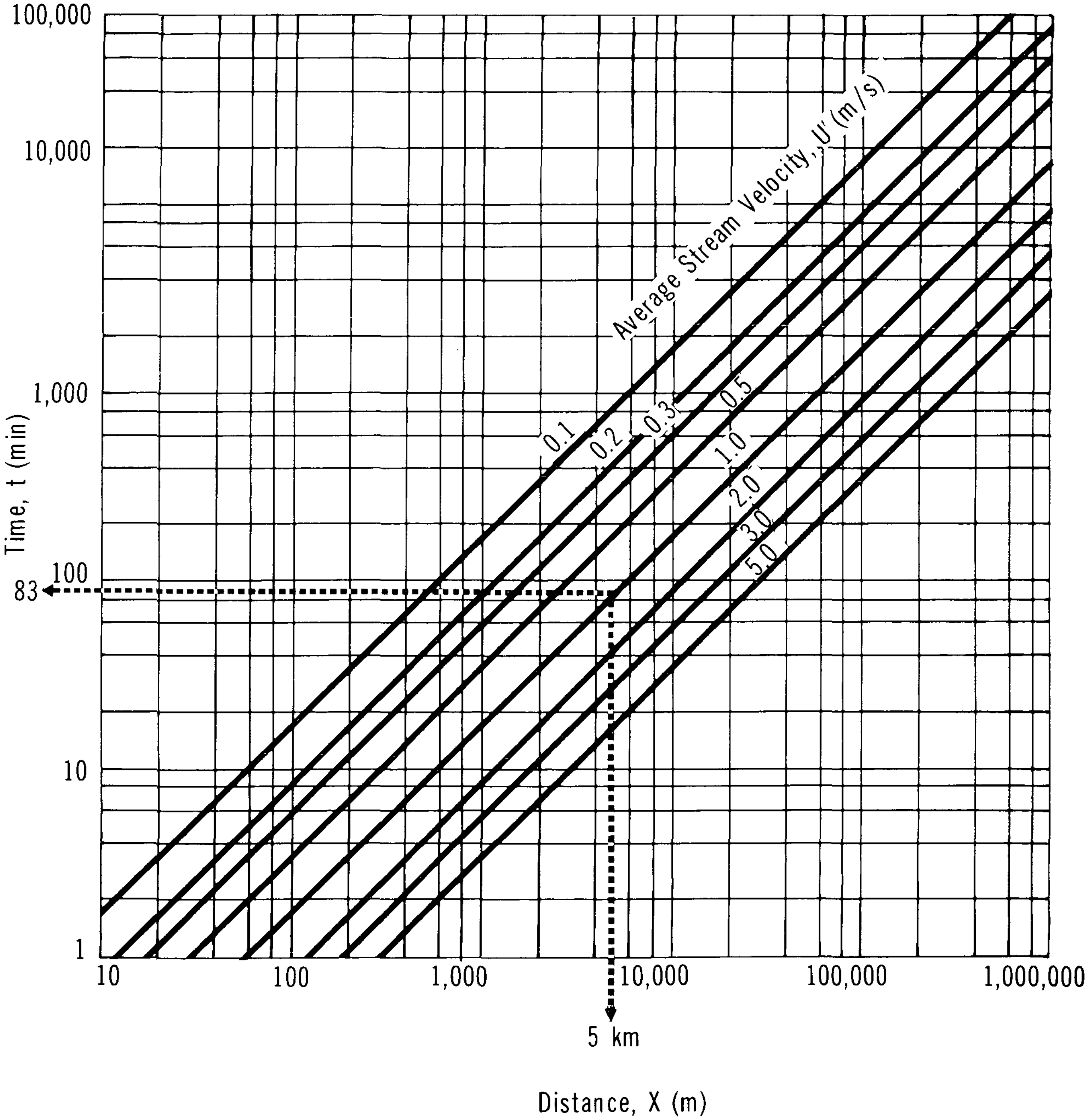
* Alpha and delta are conversion factors only and are of no significance other than to facilitate calculation of downstream concentration.

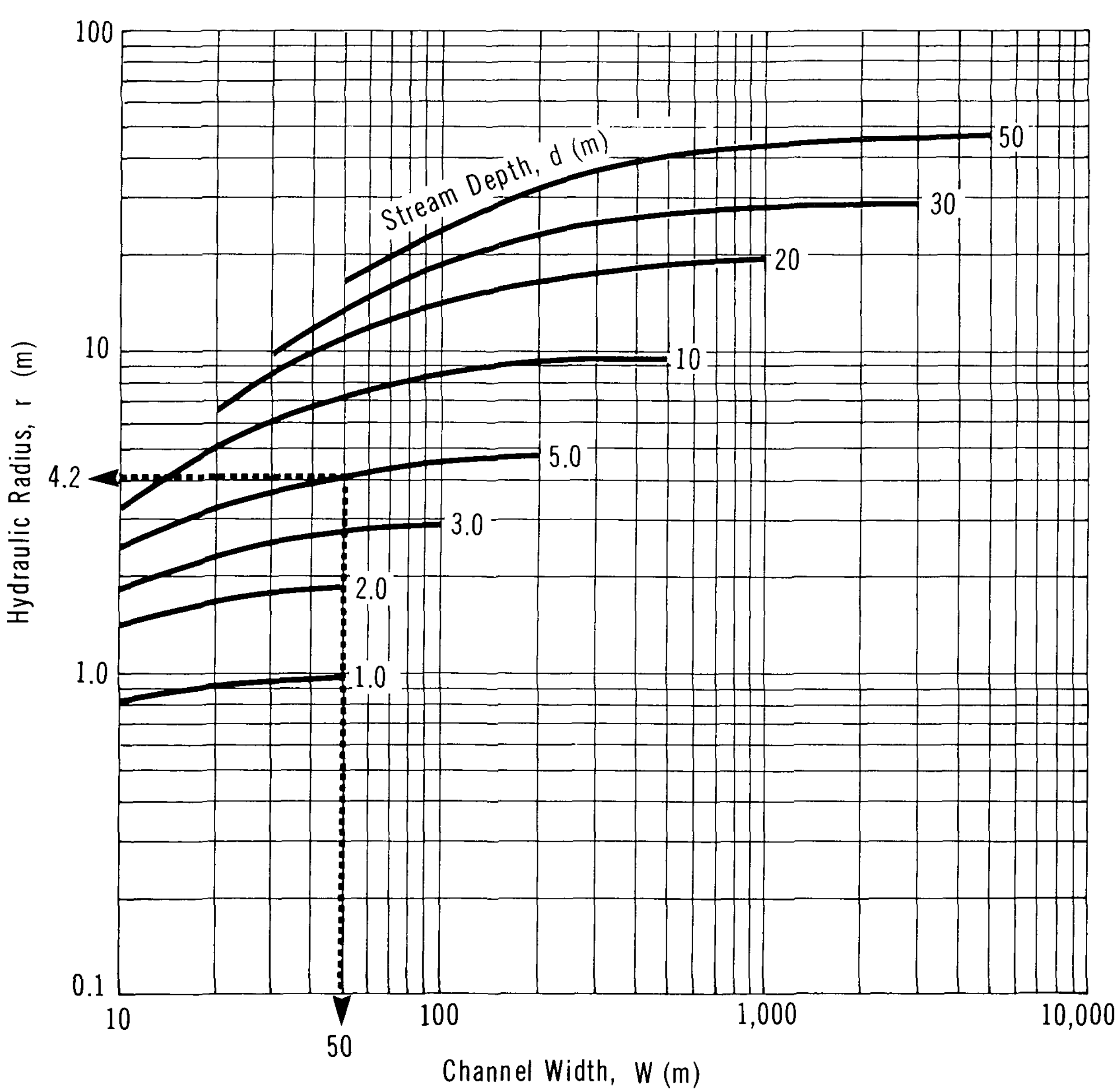
FLOW CHART TO DETERMINE POLLUTANT CONCENTRATION IN NON-TIDAL RIVERS

SPILL	
DEFINE PARAMETERS STREAM WIDTH (W) STREAM DEPTH (d) AVERAGE VELOCITY (U) SPILL MASS DOWNSTREAM DISTANCE (X)	Step 1: Observed or Estimated W = ________ m d = ________ m U = ________ m/s MASS = ________ tonnes X = ________ m
CALCULATE TIME (t) TO REACH POINT OF INTEREST	Step 2: Use Figure 15 t = ________ minutes
CALCULATE HYDRAULIC RADIUS (r) OF CHANNEL	Step 3: Use Figure 16 r = ________ m
CALCULATE LONGITUDINAL DIFFUSION COEFFICIENT (E)	Step 4: Use Figure 17 E = ________ m^2/s
CALCULATE ALPHA (α) AT TIME (t)	Step 5: Use Figure 18 α = ________
CALCULATE DELTA (Δ) FOR SPILL MASS	Step 6: Use Figure 19 Δ = ________
COMPUTE $A = W \times d$	Step 7: Compute stream cross-sectional Area (A) $A = W \times d$ ____ m^2
CALCULATE MAXIMUM CONCENTRATION (C) FOR STREAM CROSS-SECTIONAL AREA (A)	Step 8: Use Figure 20 C = ________ ppm



Time, t (min)
100,000
10,000
1,000
100
83
10
1
10
100
1,000
10,000
100,000
1,000,000
5 km
Average Stream Velocity, U (m/s)
0.1
0.2
0.3
0.5
1.0
2.0
3.0
5.0
Distance, X (m)

HYDRAULIC RADIUS VS CHANNEL WIDTH



the turbulent diffusion coefficient (E). The hydraulic radius (r) is defined as the stream cross-sectional area (A) divided by the wetted perimeter (P). Figure 16 is a nomogram for computation of the hydraulic radius (r) using the width and depth of the idealized river cross-section.

Figure 17: Diffusion coefficient versus hydraulic radius. Figure 17 permits calculation of the longitudinal diffusion coefficient (E), knowing the hydraulic radius (r) from Figure 16 and the average stream velocity (U).

Figure 18: Alpha versus diffusion coefficient. Figure 18 is used to estimate a conversion factor alpha (α), which is a function of the diffusion coefficient (E) and the time (t) to reach the point of interest downstream of the spill.

Figure 19: Alpha versus delta. A second conversion factor, delta (Δ), must be estimated from Figure 19 to allow determination of pollutant concentration at the point of interest. Delta (Δ) is a function of alpha (α) and the spill mass.

Figure 20: Maximum concentration versus delta. Figure 20 represents the final step for calculation of the maximum downstream pollutant concentration (C) at the point of interest. Using the factor delta (Δ) and knowing the stream cross-sectional area (A), the concentration (C) is readily obtained from the nomogram. The value obtained from Figure 20 applies to neutrally buoyant liquids or solids and will vary somewhat for other pollutants which are heavier or lighter than water.

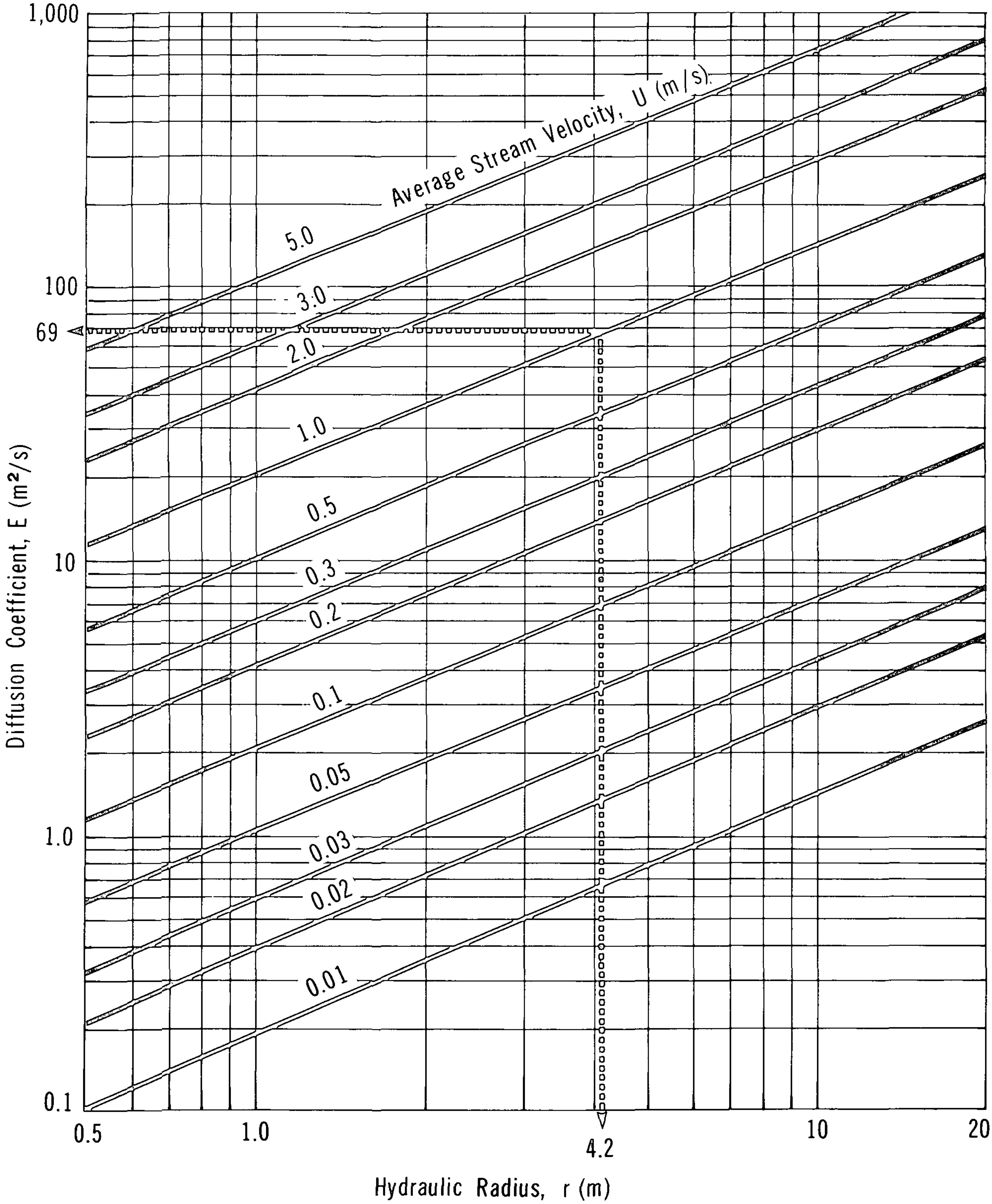
5.4.2.2 Nomograms for lakes or still water bodies.

Figure 21: Volume versus radius. The spill of a neutrally buoyant liquid in a lake in the absence of wind and current has been idealized as a cylinder of radius (r) and length (d), equivalent to the depth of the lake at the point of spill. The volume of water in the cylinder can be obtained from Figure 21. The radius (r) represents the distance from the spill to the point of interest.

Figure 22: Average concentration versus volume. For a known volume of water (within the idealized cylinder of radius (r) and length (d)), the average concentration of pollutant (C) can be obtained from Figure 22 for a known mass of spill. This assumes the pollutant is spread evenly throughout the cylinder. For pollutants that are more or less dense than water, the actual concentration at the bottom would be higher or lower, respectively.

CALCIUM CHLORIDE

DIFFUSION COEFFICIENT VS HYDRAULIC RADIUS



CALCIUM CHLORIDE

ALPHA vs DIFFUSION COEFFICIENT

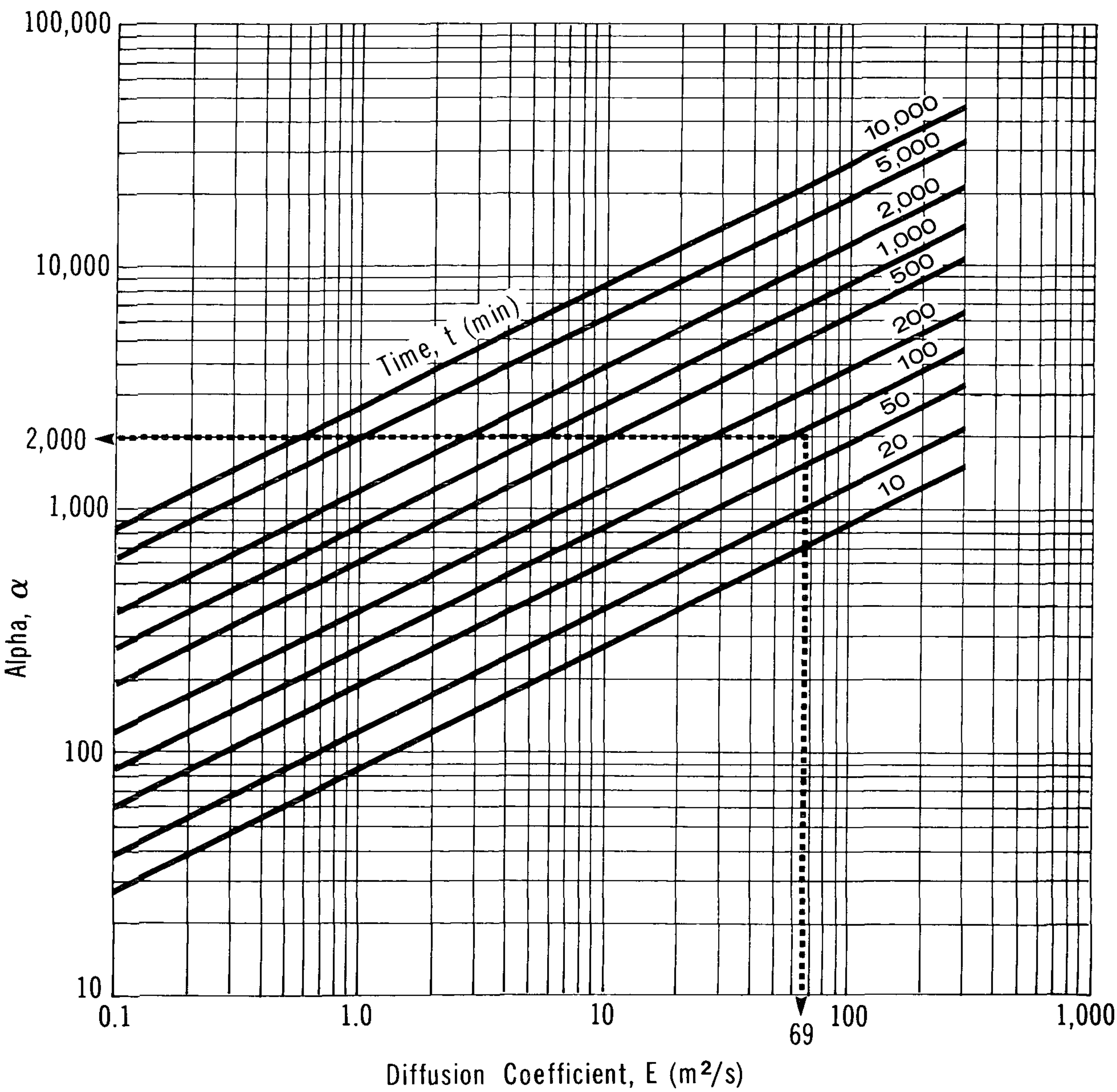
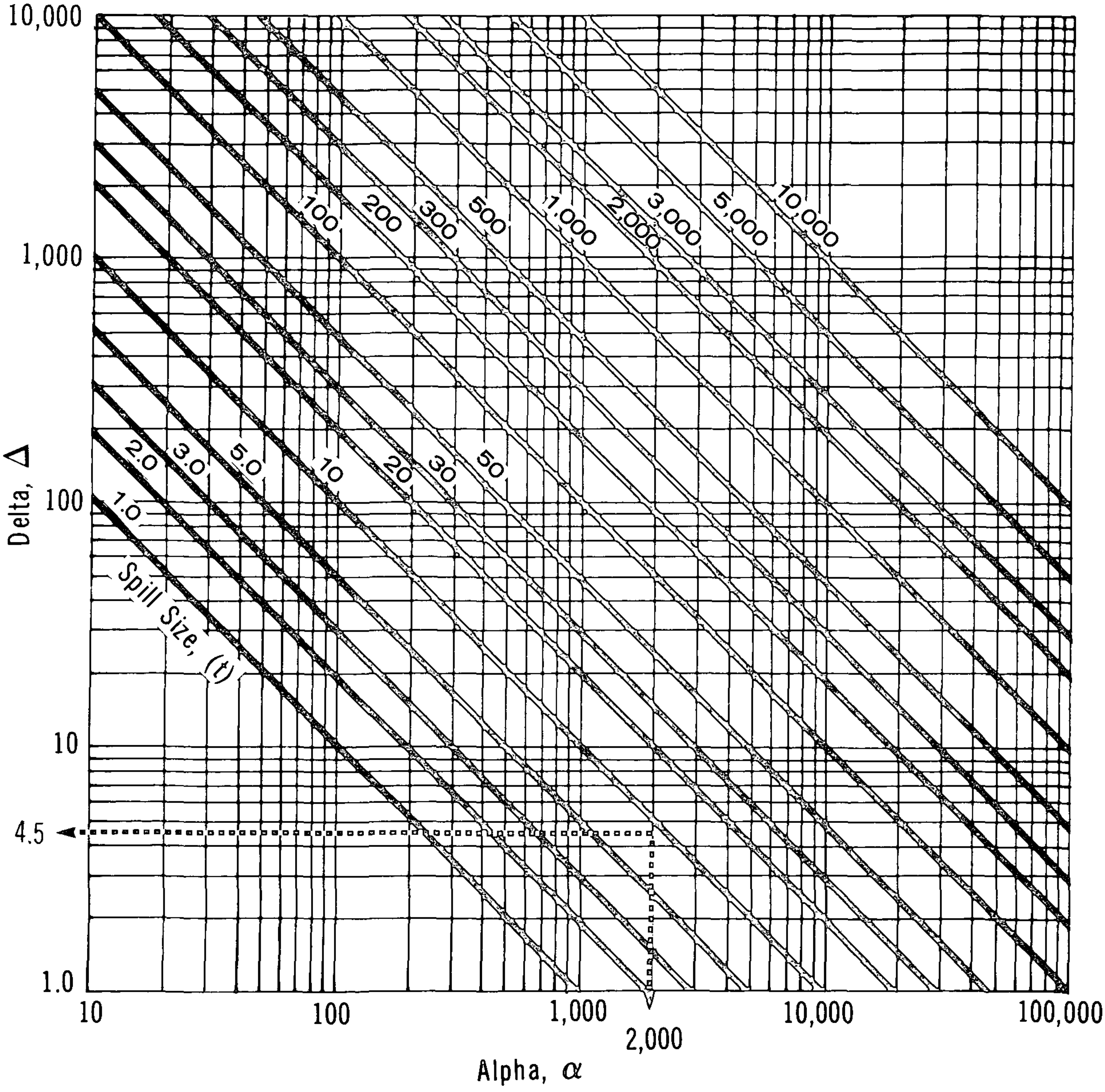


FIGURE 19

CALCIUM CHLORIDE

ALPHA vs DELTA



CALCIUM CHLORIDE

MAXIMUM CONCENTRATION vs DELTA

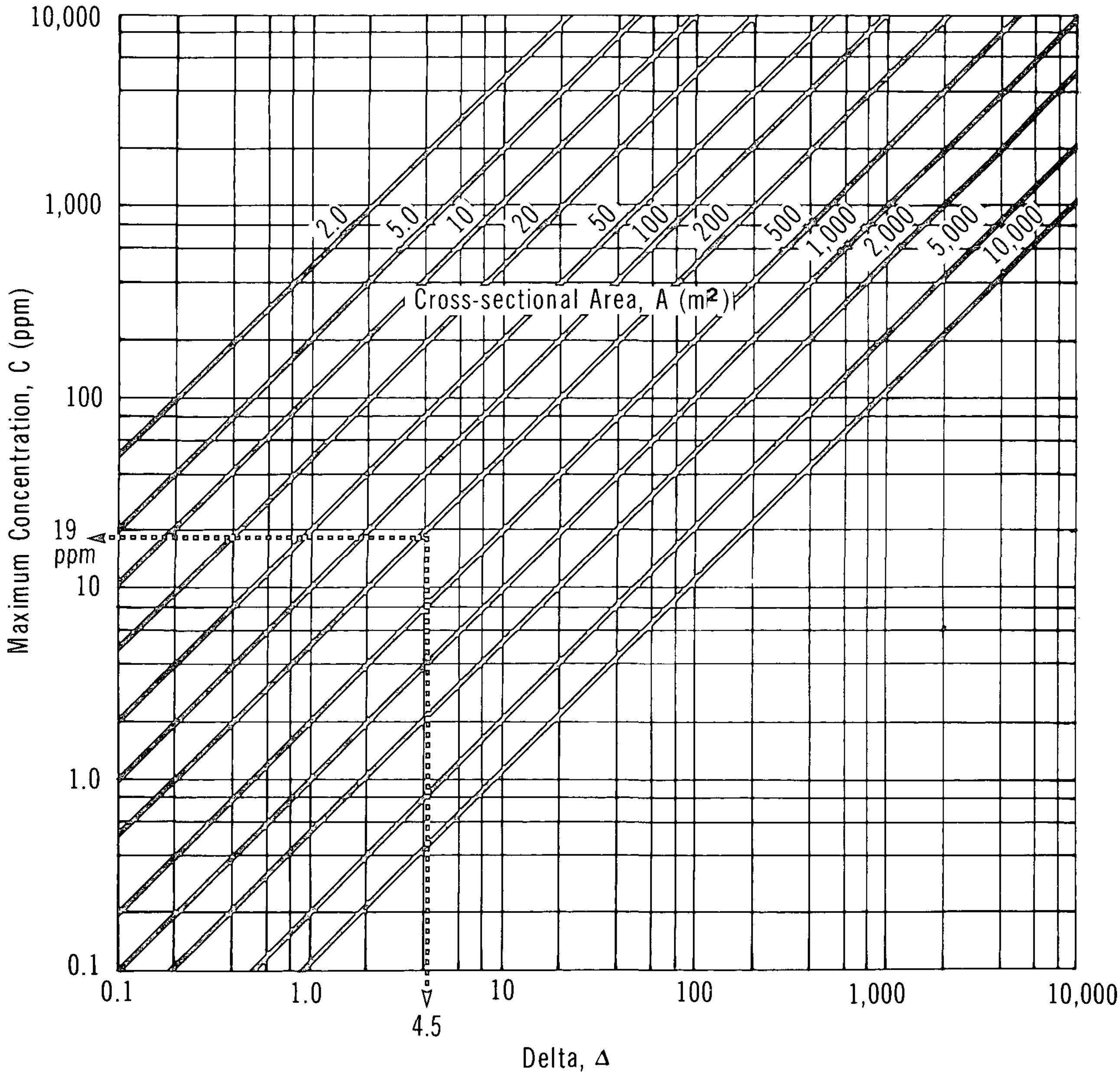
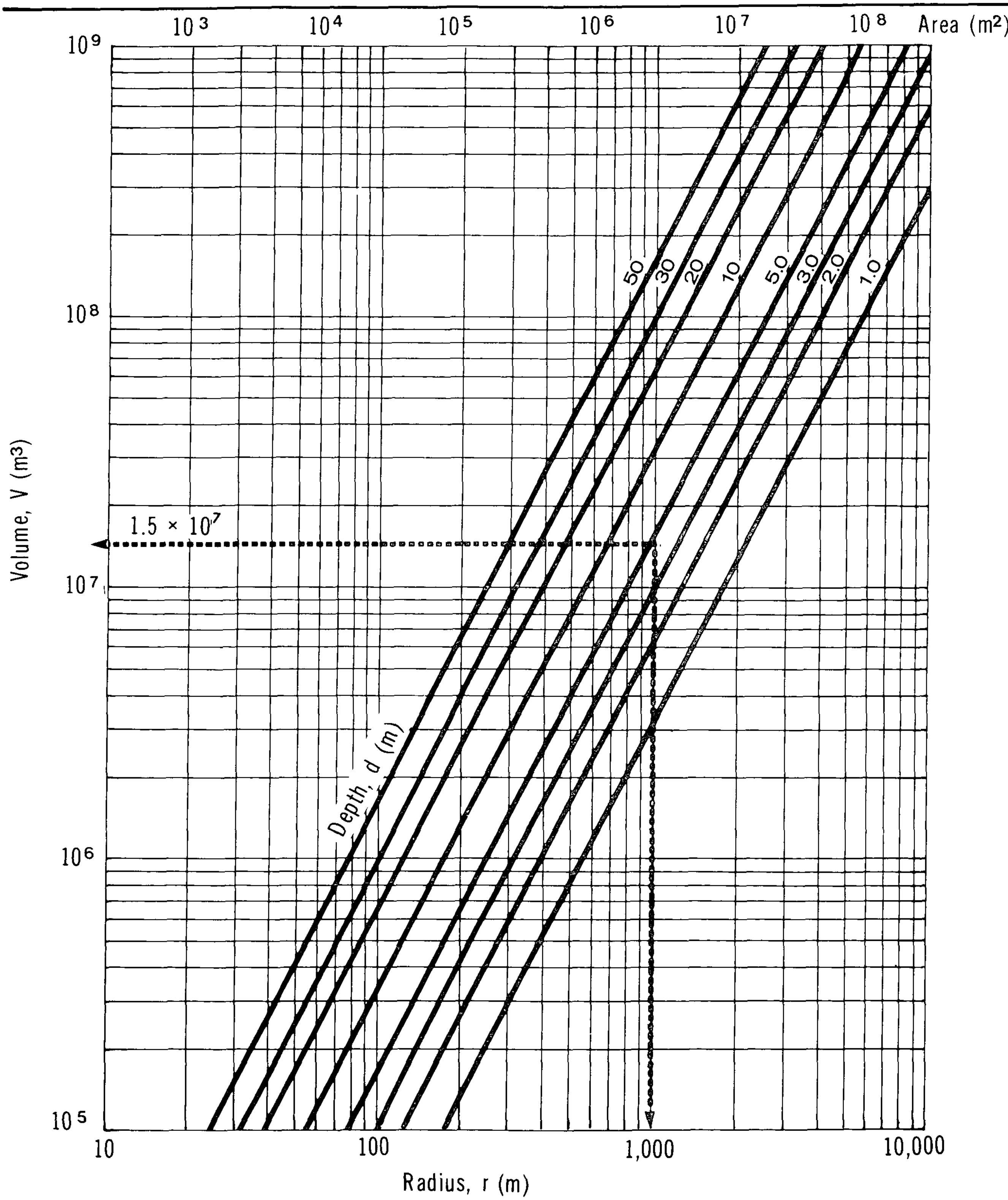


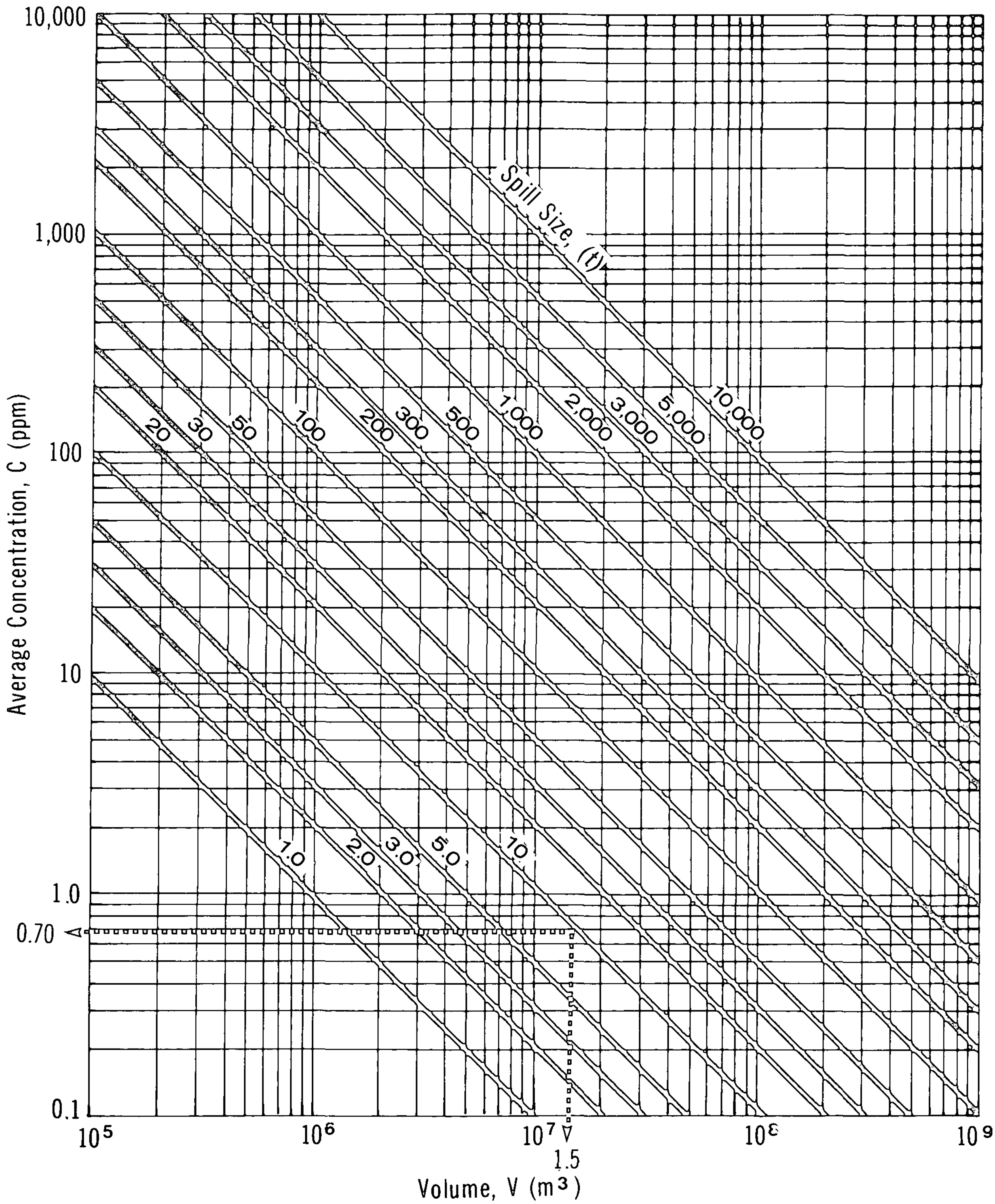
FIGURE 21

CALCIUM CHLORIDE

VOLUME vs RADIUS



AVERAGE CONCENTRATION vs VOLUME



5.4.3 Sample Calculations.

5.4.3.1 Pollutant concentration in non-tidal river. A 20 tonne spill of 45 percent calcium chloride liquor has occurred in a river. The stream width is 50 m and the stream depth is 5 m. The average stream velocity is estimated at 1 m/s. What is the maximum concentration expected at a water intake located 5 km downstream?

Solution

Step 1: Define parameters

- W = 50 m
- d = 5 m
- U = 1 m/s
- spill mass = 20 tonnes of 45 percent liquor, equivalent to 9 tonnes of 100 percent calcium chloride
- X = 5,000 m

Step 2: Calculate time to reach point of interest

- Use Figure 15
- With X = 5,000 m and U = 1 m/s, t = 83 min

Step 3: Calculate hydraulic radius (r)

- Use Figure 16
- With W = 50 m and d = 5 m, r = 4.2 m

Step 4: Calculate longitudinal diffusion coefficient (E)

- Use Figure 17
- With r = 4.2 m and U = 1 m/s, E = 69 m^2/s

Step 5: Calculate alpha (α)

- Use Figure 18
- With E = 69 m^2/s and t = 83 min, α = 2,000

Step 6: Calculate delta (Δ)

- Use Figure 19
- With alpha (α) = 2,000 and spill mass = 9 tonnes (100 percent calcium chloride), delta (Δ) = 4.5

Step 7: Compute stream cross-sectional area (A)

- $A = W \times d = 50 \times 5 = 250\ m^2$

Step 8: Calculate maximum concentration (C) at point of interest

- Use Figure 20
- With $\Delta = 4.5$ and $A = 250\ m^2$, C = 19 ppm

5.4.3.2 Average pollutant concentration in lakes or still water bodies. A 20 tonne spill of 45 percent calcium chloride liquor has occurred in a lake. The point of interest is located on the shore approximately 1 000 m from the spill. The average depth between the spill site and the point of interest is 5 m. What is the average concentration which could be expected?

Solution

Step 1: Define parameters

- d = 5 m
- r = 1 000 m
- spill mass = 9 tonnes (equivalent)

Step 2: Determine the volume of water available for dilution

- Use Figure 21
- With r = 1 000 m, d = 5 m, the volume is approximately $1.5 \times 10^7\ m^3$

Step 3: Determine the average concentration

- Use Figure 22
- With $V = 1.5 \times 10^7\ m^3$ and mass = 9 tonnes, the average concentration is 0.7 ppm

5.5 Subsurface Behaviour: Penetration into Soil

5.5.1 Mechanisms. The principles of contaminant transport in soil and their application to this work are presented in the Introduction Manual. Special considerations related to the spill of calcium chloride onto soil and its transport downward through the soil are presented here.

Calcium chloride is transported frequently as a solid. Consequently, when spilled, only limited groundwater contamination hazard exists if the soil is dry and if no precipitation falls prior to cleanup. However, if precipitation or other forms of moisture are present, groundwater contamination can be expected.

Since calcium chloride is very soluble (42.5 g/100 mL at 20°C), strong salt solutions can infiltrate the soil. Some interaction between $CaCl_2$ and the soil, probably in the form of ion exchange, will occur. However, much of the salt together with exchanged ions will migrate downward through the soil. If the soil surface is saturated with moisture at the time of the spill, as might be the case after a rainfall, the spilled chemical may run off in surface water.

The soils have been assumed to be at field capacity (the maximum amount the soil will retain after excess water is drained off). This situation provides very little interstitial water to dilute the chemical during transport or to impede its downward movement and thus represents "worst case" analysis.

Upon reaching the groundwater table, the contaminant will continue to move, now in the direction of groundwater flow. A contaminated plume will be produced, with diffusion and dispersion serving to reduce the concentration somewhat. This is shown schematically in Figure 23.

5.5.2 Equations Describing Calcium Chloride Movement into Soil. The equations and assumptions used to describe contaminant movement in solution downward through the unsaturated soil zone toward the groundwater table have been described in the Introduction Manual. Transport velocities have been based on Darcy's Law assuming saturated piston flow.

5.5.3 Saturated Hydraulic Conductivity of Calcium Chloride Solutions in Soil. The saturated hydraulic conductivity (K_o), in m/s, is given by:

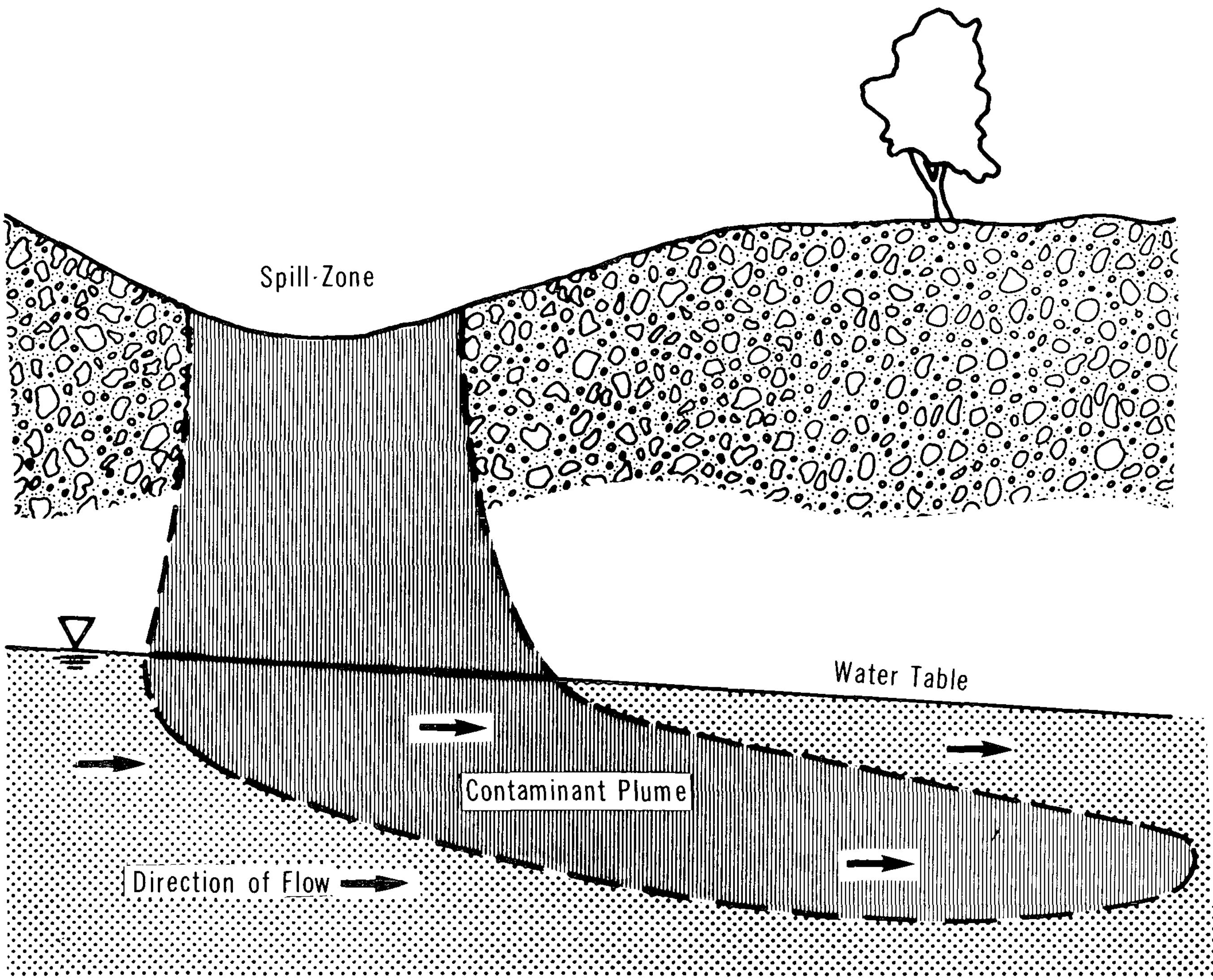
$$K_o = \frac{(\rho g)k}{\mu}$$

where:

k	=	intrinsic permeability of the soil (m^2)
ρ	=	mass density of the fluid (kg/m^3)
μ	=	absolute viscosity of the fluid (Pa·s)
g	=	acceleration due to gravity = 9.81 m/s^2

The fluids involved are water and a 30 percent by weight solution of calcium chloride, an example of a strong solution. The water calculations represent the extreme as the $CaCl_2$ solution is diluted.

SCHEMATIC SOIL TRANSPORT



Soil: Coarse Sand

–Porosity (n) = 0.35

–Intrinsic Permeability (k) = 10^{-9} m^2

–Field Capacity (θ_{fc}) = 0.075

Property	Calcium Chloride (30%) 20°C	Calcium Chloride (30%) 4°C	Water 20°C
Mass density (ρ), kg/m^3	1,282	1,284	998
Absolute viscosity (μ), Pa·s	3.5×10^{-3}	2.5×10^{-3}	1.0×10^{-3}
Saturated hydraulic conductivity (K_o), m/s	$(0.36 \times 10^7)k$	$(0.49 \times 10^7)k$	$(0.98 \times 10^7)k$

5.5.4 Soils. The Introduction Manual describes the three soils selected for this work. Their relevant properties are:

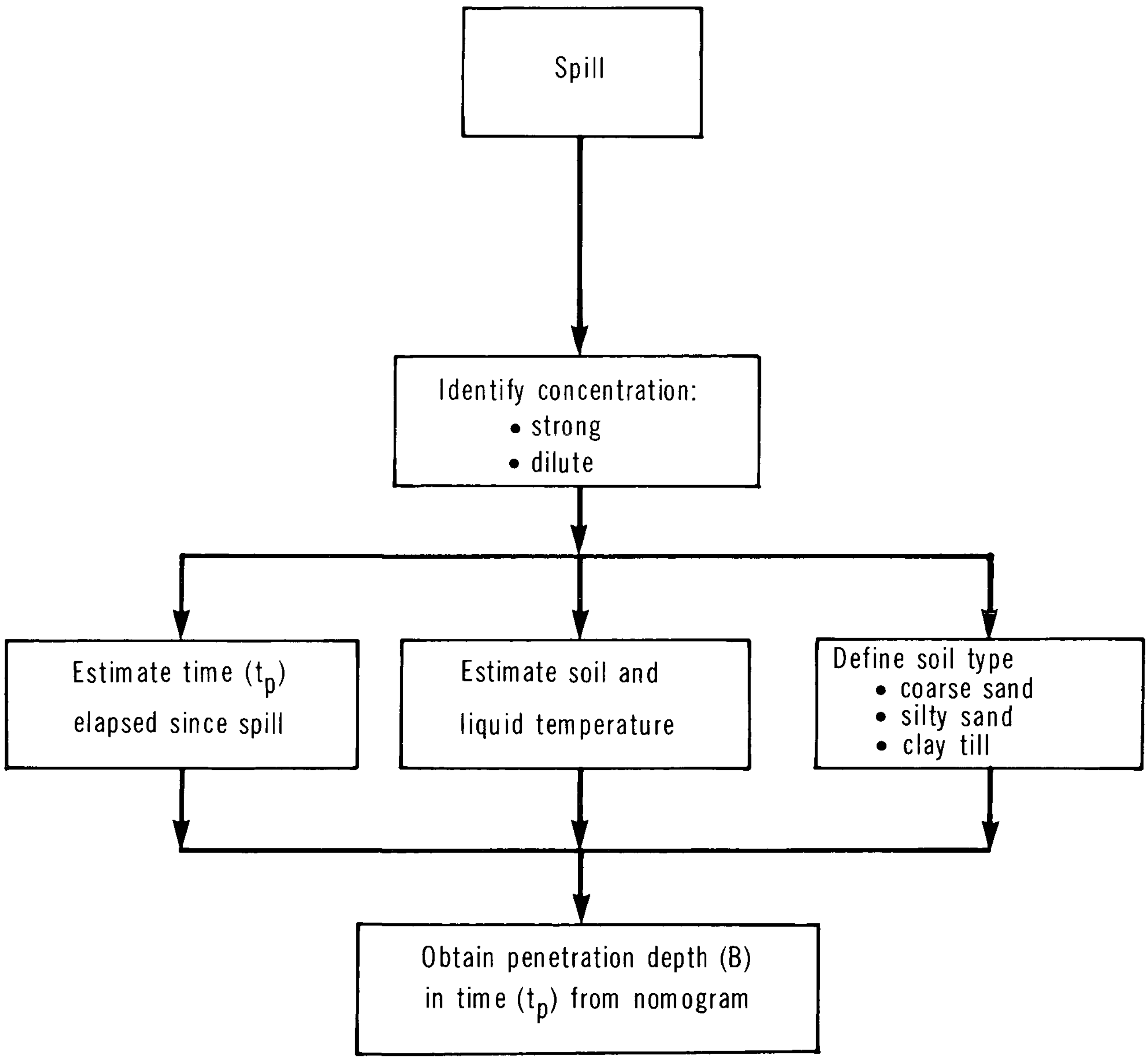
Property	Soil Type: Coarse Sand	Silty Sand	Clay Till
Porosity (n), m^3/m^3	0.35	0.45	0.55
Intrinsic permeability (k), m^2	10^{-9}	10^{-12}	10^{-15}
Field capacity (θ_{fc}), m^3/m^3	0.075	0.3	0.45

5.5.5 Penetration Nomograms. Nomograms for the penetration of calcium chloride into the unsaturated zone above the groundwater table were prepared for each soil. They present penetration time (t_p) plotted against depth of penetration (B). Because of the methods and assumptions used, the penetration depth should be considered as a maximum depth in time t_p.

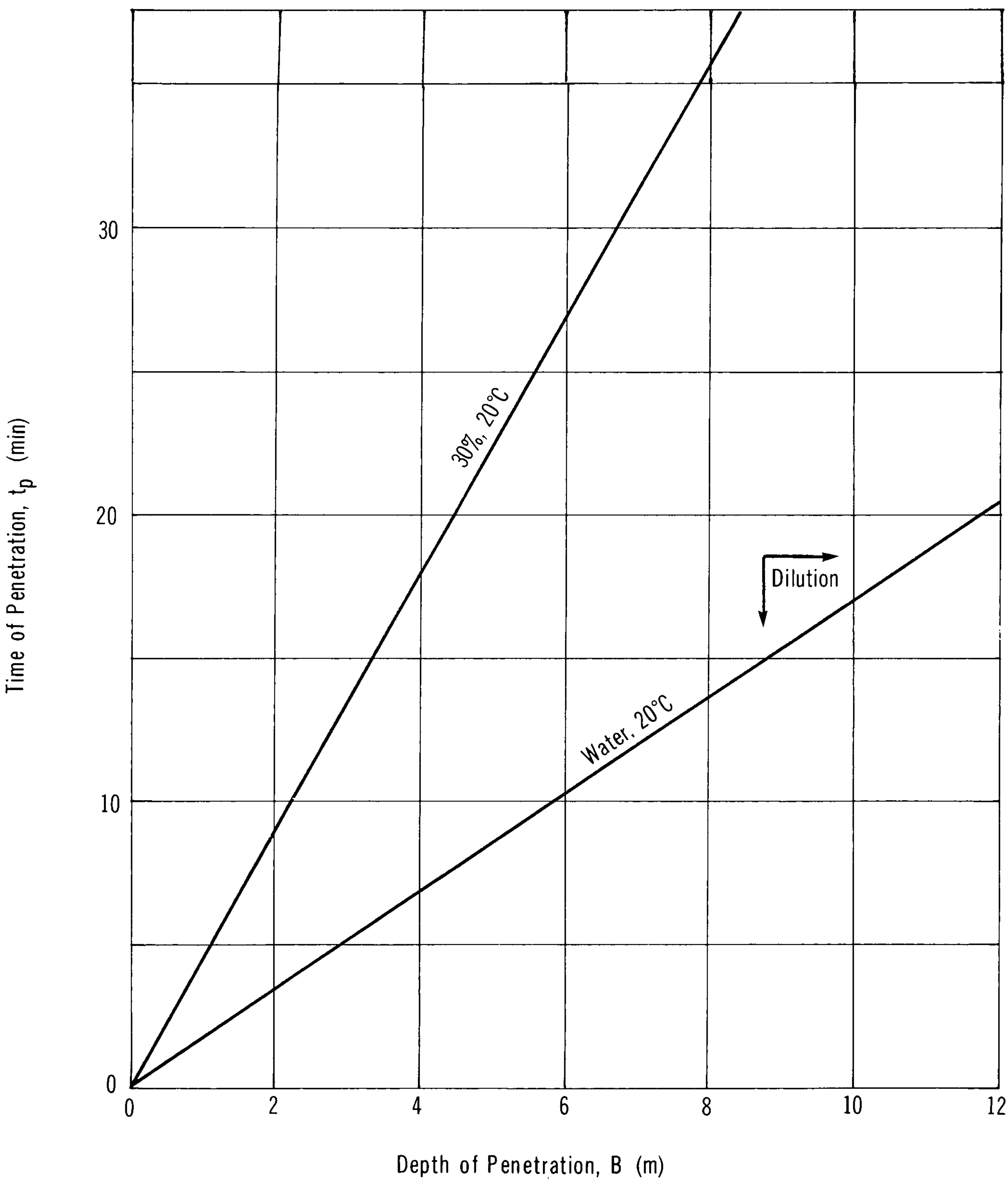
A flowchart for the use of the nomograms is presented in Figure 24. The nomograms are presented as Figures 25, 26 and 27. The water line on the nomograms represents the maximum penetration of water at 20°C in time t_p. It is a limiting condition as calcium chloride becomes diluted with water.

5.5.6 Sample Calculation. A 20 tonne spill of calcium chloride has occurred on coarse sand. The temperature is 20°C; the spill radius is 8.6 m. During cleanup, it begins to rain. Calculate the depth of penetration 20 minutes after the rain has started.

FLOWCHART FOR NOMOGRAM USE

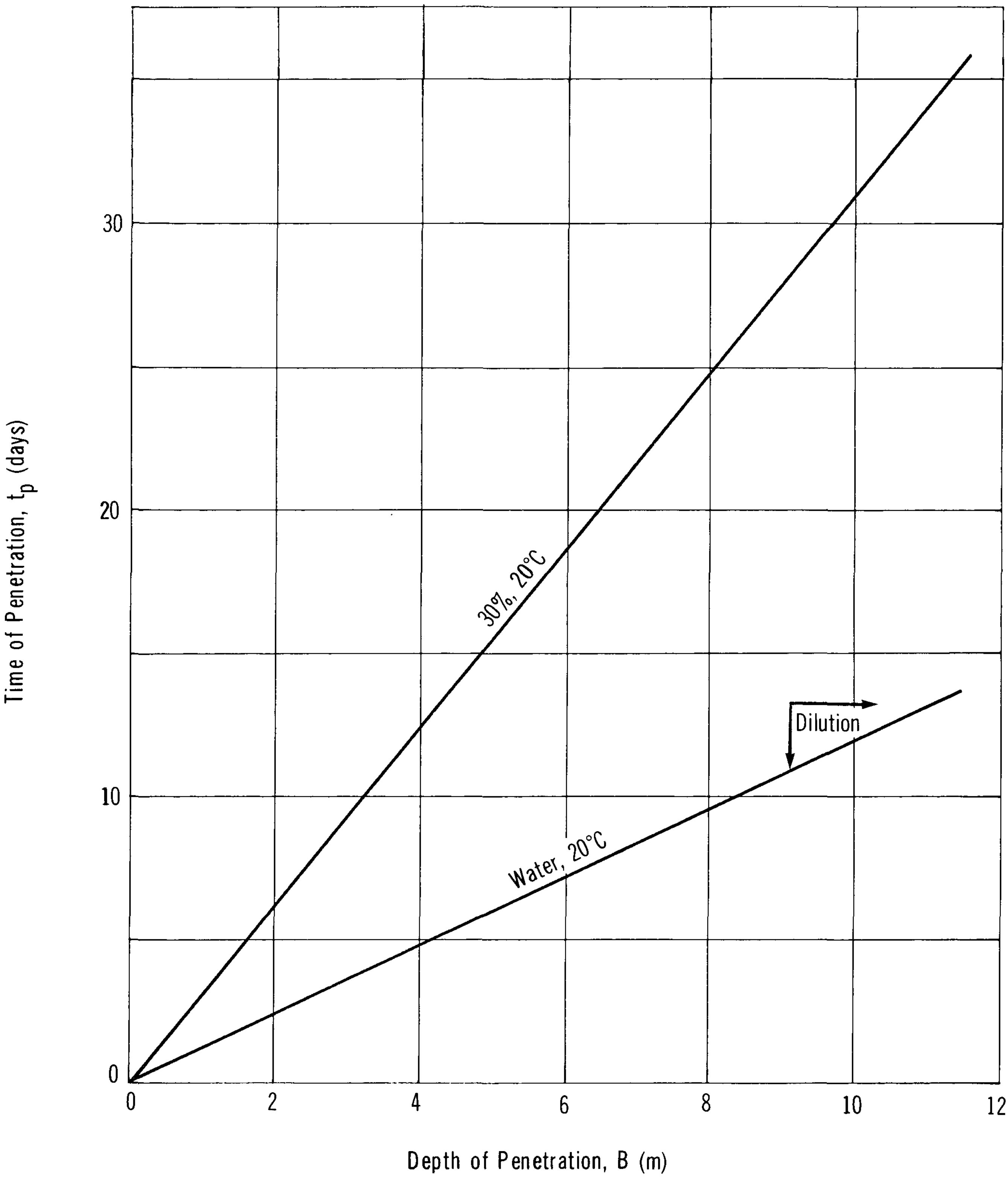


PENETRATION IN COARSE SAND



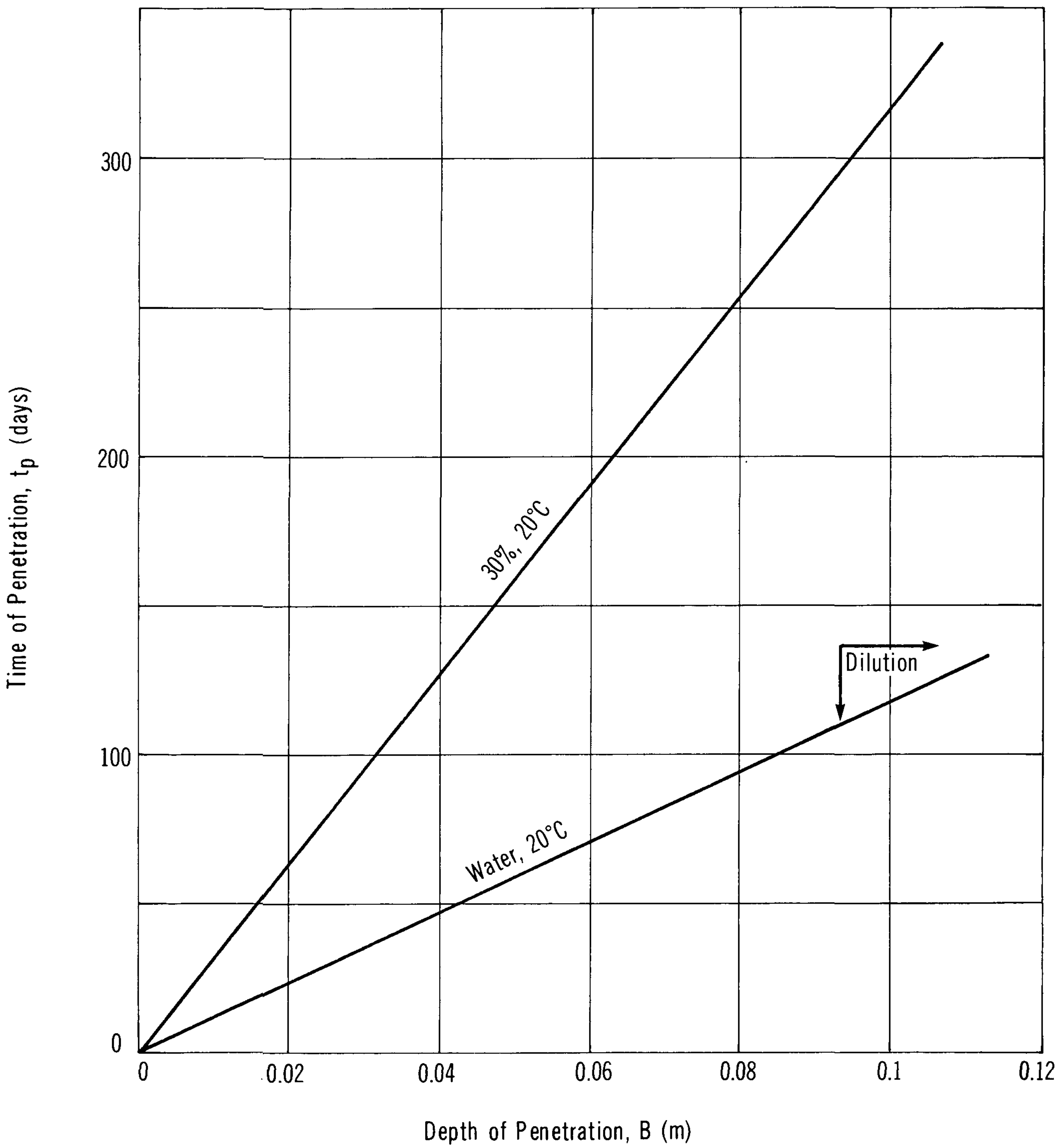
CALCIUM CHLORIDE

PENETRATION IN SILTY SAND



CALCIUM CHLORIDE

PENETRATION IN CLAY TILL



Solution

Step 1: Define parameters

- Mass spilled = 20,000 kg (20 tonnes)
- T = 20°C
- r = 8.6 m
- Soil = coarse sand
- Groundwater table depth (d) = 13 m
- Time since rain (t_p) = 20 min

Step 2: Calculate area of spill

- $A = \pi r^2 = 232\ m^2$

Step 3: Estimate depth of penetration (B) at time (t_p)

- For coarse sand, and t_p = 20 min, using Figure 25, the penetration range is:

  9.3 m for a 30 % solution
  11.9 m for a dilute solution (water, worst case)

- Groundwater table has not been reached at this point

6 ENVIRONMENTAL DATA

6.1 Suggested or Regulated Limits

6.1.1 Water. 500 mg/L has been recommended as a drinking water limit to avoid salty taste. However, concentrations as low as 50 mg/L may be objectionable (WQC 1963).

For irrigation, 350 mg/L has been recommended as a limit; for long-term use, 100 mg/L is preferred. For livestock use, limits of 1,000 and 500 mg/L have been proposed, the latter for chloride toxicity (Todd 1970).

6.1.2 Air. In Canada, there are no regulations governing airborne calcium chloride levels.

6.2 Aquatic Toxicity

6.2.1 U.S. Toxicity Rating. Calcium chloride has been assigned a TL_m96 (4-day median lethal toxicity rating) of greater than 1,000 mg/L (RTECS 1979).

6.2.2 Measured Toxicities.

6.2.2.1 Freshwater toxicity.

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
Fish Kill Data					
555	168	Rock bass	killed	tap	WQC 1963
2,775	48	Minnows	killed	distilled	WQC 1963
5,000	142	Shiners	killed		WQC 1963
7,752	22	Goldfish	killed		WQC 1963
Fish Toxicity Tests					
8,400	24	Bluegill	TL_m	synthetic	WQC 1963
9,500	96	Bluegill	TL_m	standard	WQC 1963
10,650	96	Sunfish	TL_m		WQC 1963
13,400	96	Mosquito fish	TL_m	turbid	WQC 1963
12,060	not stated	Pickerel fry	immobilized	Lake Erie	WQC 1963
22,080	not stated	Whitefish fry	immobilized	Lake Erie	WQC 1963

Conc. (mg/kg)	Species	Result	Reference
Vertebrates			
660	Frog	LD_{LO} (subcutaneous)	RTECS 1979

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
Microorganisms					
900	64	*Daphnia magna*	threshold	Lake Erie	Anderson 1948
3,130	120	*Nitzschia linearis*	LC_{50}	static	WQCDB-5 1973

6.2.2.2 Saltwater toxicity.

Conc. (mg/L)	Time (hours)	Species	Result	Water Conditions	Reference
Fish Toxicity Test					
2,400	48	Marine fish	TL_m	sea water	OHM-TADS 1981

6.3 Toxicity to Other Biota

6.3.1 Livestock.

Conc. (mg/L)	Animal	Result	Reference
10,000 to 15,000	Cow	moderate effect on nerves, appetite	WQC 1963
20,000 to 25,000	Sheep	tolerated for 6 weeks	WQC 1963
15,000 to 20,000	Chicken	interfered with growth	WQC 1963

6.3.2 Plants. High concentrations of calcium chloride in irrigation water will reduce plant growth. The chloride ion threshold limit for chronic plant toxicity is 100 ppm (OHM-TADS 1981).

A number of studies have been conducted on the effects of calcium chloride and sodium chloride as a result of their use as road de-icers (NRCC 1977). Damage to roadside vegetation has been reported and is attributed largely to the absorption of salt splashed on foliage. In one study, sugar maples were exposed to runoff of NaCl and $CaCl_2$ for 6 winters (total treatment of 112 tonnes/ha per treatment and 15 treatments per winter at weekly intervals). Leaves of these maple trees contained 3 to 6 times the chloride (Cl^-) concentration compared to a control stand. Damage to the maples varied but could be correlated with the chloride concentration in the leaf: 0.5 to 6 mg/g dry weight - little damage; 4 to 10 mg/g - slight damage; and >10 mg/g - severe damage (NRCC 1977). Conifers are probably more susceptible to salt spray than other vegetation. Although they do not grow during winter, they remain photosynthetically active; salt splashed onto the needles would thus have damaging effects (NRCC 1977). Grasses are less susceptible than conifers to damage probably because of their inactivity in winter. In a series of tests, Kentucky 31 Fescue was found to be the most resistant of grasses and could tolerate up to 5 g NaCl/kg of soil (NRCC 1977). Several studies have shown foliage damage where salt (NaCl and $CaCl_2$) was employed and have correlated this to the high level of chloride (Cl^-) in foliage and twigs. Some studies have noted a higher occurrence of damage on the downwind portion of roads, thus indicating that sprayed salt has a higher potential for damage than that transmitted through the soil (NRCC 1977).

A generally accepted index of crop response to salt (applicable to $CaCl_2$) is as follows (NRCC 1977):

Salt Concentration (g/L of soil)	Effect on Yield
0 - 1.3	Salinity effects negligible
1.3 - 2.6	Yields of sensitive crops affected
2.6 - 5.1	Yields of many crops restricted
5.1 - 10.2	Only tolerant crops yield satisfactorily
>10.2	Only a few very tolerant crops yield satisfactorily

6.4 Effect Studies

6.4.1 Animals. The acute toxicity of calcium chloride for mammals is a LD_{50} (oral) of 1,000 to 5,000 mg/kg (WQCDB-2 1971).

6.5 Degradation

Calcium chloride does not biodegrade; calcium levels in water are controlled by carbonate levels and pH (OHM-TADS 1981).

6.6 Long-term Fate and Effects

Calcium chloride does not bioaccumulate or have food chain contamination potential.

7 HUMAN HEALTH

Calcium chloride is a nonvolatile substance under normal conditions, thus limiting routes of exposure. Consequently, no data have been accumulated on the health effects of inhalation of calcium chloride in man or in animals. Published literature indicates that exposure to calcium chloride dust causes irritation to the eyes and throat while solutions can cause burns and eye damage when tissue contact is made. Prolonged exposure can cause serious burns, especially on previously injured tissue.

No data were found in the literature pertaining to any mutagenic, carcinogenic or teratogenic effects of the compound on man, animals or organisms.

Calcium chloride has been reported in the EPA TSCA inventory (RTECS 1979). The data summarized here are representative of information found in the literature. The toxicological data summarized here have been extracted from reliable standard reference sources. It should be noted that some of the data are for chronic (long-term), low-level exposures and may not be directly applicable to spill situations.

7.1 Recommended Exposure Limits

Established exposure limits for calcium chloride were not encountered in the literature.

7.2 Irritation Data

7.2.1 Skin Contact.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
-	Contact of solid with dry skin causes mild irritation; strong solutions can cause marked irritation, even a superficial burn	CHRIS 1978
-	Solution or solid will burn skin	CHRIS 1978

7.2.2 Eye Contact.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
-	Dust causes irritation and possible transient corneal injury	CHRIS 1978
-	Solution or solid will burn eyes	CHRIS 1978

7.3 Threshold Perception Properties

7.3.1 Odour. Odourless (CHRIS 1978)

7.3.2 Taste.

Parameter	Media	Concentration	Reference
Detection	In water	0.01 moles/L	ASTM 1980
Detection	In water	0.0076 moles/L	ASTM 1980

7.4 Long-term Studies

7.4.1 Inhalation. No data have been reported.

7.4.2 Ingestion.

Exposure Level (and Duration)	Effects	Reference
Acute Exposures		
SPECIES: Human		
	No data	
SPECIES: Rat		
1,000 mg/kg	LD_{50}	RTECS 1979
SPECIES: Rabbit		
1,384 mg/kg	LD_{LO}	RTECS 1979

7.4.3 Subcutaneous.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Dog		
274 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Cat		
249 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Rabbit		
472 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Frog		
666 mg/kg	LD_{LO}	RTECS 1979

7.4.4 Intravenous.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Dog		
274 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Cat		
249 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Rabbit		
274 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Rat		
161 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Mouse		
42 mg/kg	LD_{50}	RTECS 1979

7.4.5 Intraperitoneal.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Dog		
110 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Rat		
500 mg/kg	LD_{LO}	RTECS 1979
SPECIES: Mouse		
280 mg/kg	LD_{50}	RTECS 1979

7.4.6 Intramuscular.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Rat		
25 mg/kg	LD_{50}	RTECS 1979

7.4.7 Route of Exposure Not Specified.

Exposure Level (and Duration)	Effects	Reference
SPECIES: Human		
Calcium chloride, 7 mg/kg, and calcium gluconate, 20 mg/kg	Administered to patients with low or low-normal levels of serum ionized calcium, low blood pressure and other abnormalities. Resulted in increased serum ionized calcium levels, decreased serum potassium levels, and development of severe cardiac arrhythmias	Toxline (on-line) 1981

7.5 Symptoms of Exposure

General symptoms of exposure found in most information sources have not been specifically referenced. Only those of a more specific or unusual nature have their sources indicated.

7.5.1 Inhalation.

1. Irritation of nose and throat.
2. Causes nose bleeds (TDB (on-line) 1981).

7.5.2 Ingestion.

1. Irritation of mouth and stomach.
2. Nausea and vomiting.

7.5.3 Skin Contact.

1. Irritation.
2. Burns from strong solutions.
3. Mild irritation when solid contacts dry skin.

7.5.4 Eye Contact.

1. Irritation and eye discharge.
2. Possible transient corneal damage, particularly with dust.

8 CHEMICAL COMPATIBILITY

8.1 Compatibility of Calcium Chloride with Other Chemicals and Chemical Groups

SPECIFIC CHEMICAL OR CHEMICAL GROUP	HEAT GENERATION	FIRE	EXPLOSION	FORMATION OF FLAMMABLE GASES	VIOLENT POLYMERIZATION	DECOMPOSITION	FORMATION OF TOXIC FUMES	FORMATION OF SUBSTANCES OF GREATER TOXICITY	PRESSURIZATION IN CLOSED VESSELS	SOLUBILIZATION	VIOLENT REACTION	NON-HAZARDOUS REACTION	SPECIFICS	REFERENCE
<u>GENERAL</u>														
Water	x												Reacts with water exothermically (not violent)	Bretherick 1979
<u>SPECIFIC CHEMICALS</u>														
Bromine Trifluoride											x		Attacks calcium chloride	NFPA 1978
Furan-2-Peroxy-carboxylic Acid			x										Explodes upon addition of calcium chloride	NFPA 1978
Methyl Vinyl Ether	x				x								Initiates exothermic polymerization	Bretherick 1979
Zinc				x									Evolves hydrogen upon prolonged contact	Bretherick 1979

9 COUNTERMEASURES

9.1 Recommended Handling Procedures

The following procedures have been derived from a literature review. To avoid any deviation from the intended meaning, the wording of the original source has been presented essentially unchanged - in so doing, it is recognized that there may be some discrepancies between different sources of information. It is recognized that countermeasures are dependent on the situation, and thus what may appear to be conflicting information may in fact be correct for different situations. These procedures should not be considered as Environment Canada's recommendations.

9.1.1 Fire Concerns. Calcium chloride is a nonflammable material (Hooker MSDS 1972). The anhydrous, monohydrate, dihydrate and tetrahydrate forms of calcium chloride, when dissolved in water, produce considerable amounts of heat (Allied TESB 1958).

9.1.2 Fire Extinguishing Agents. Calcium chloride is not combustible; most fire-fighting agents can be used on fires involving calcium chloride (Dow ERIS 1979).

9.1.3 Spill Actions, Cleanup and Treatment.

9.1.3.1 General. Stop or reduce discharge of material if this can be done without risk. Avoid skin contact and inhalation (Dow ERIS 1979).

9.1.3.2 Spills on land. When solid calcium chloride is spilled on land, shovel into containers (avoid dusting) for recovery or disposal (Dow ERIS 1979). Solid spills - especially with a little water present - present a very slippery surface and thus should be removed with caution (CCPA 1982).

When calcium chloride solution is spilled on land, contain if possible by forming mechanical and/or chemical barriers to prevent spreading (EPA 670/2-75-042).

9.1.3.3 Spills in water. Contain if possible. Small quantities of contaminated water may be treated by adding soda ash (with a slight excess) and neutralizing the clear (decant) water with 6 M hydrochloric acid. Mixed ion exchange and reverse osmosis can also be used to treat contaminated water (OHM-TADS 1981).

9.1.4 Disposal. Waste calcium chloride must never be discharged directly into sewers or surface waters. Following treatment, either at the spill site or at a waste management facility, the resultant sludge can be disposed of to a secure landfill.

9.1.5 Protective Measures. For entry into a situation where the spilled material and its characteristics are unknown, self-contained breathing apparatus and a totally encapsulated chemical suit should be worn.

If the spilled material is known to be calcium chloride:

- Chemical safety glasses or faceshields, impervious clothing and mist protection equipment should be worn (Hooker MSDS 1972).
- Rubber boots, or well-oiled leather shoes are desirable when handling any calcium chloride product (Allied TESB 1958).
- Canvas gloves or gauntlets ordinarily are satisfactory in handling flake calcium chloride, but rubber gloves, or rubberized or latex coated canvas gauntlets are preferred for handling solutions. (Allied TESB 1958). Neoprene and vinyl should also be considered for gloves (Hooker MSDS 1972).
- A rubber or rubberized raincoat is suggested where clothing may become wet with calcium chloride solution (Allied TESB 1958).

10 PREVIOUS SPILL EXPERIENCE

This section contains information on previous spill experience which will be useful to readers in understanding spill response and countermeasures. Only those which meet this criterion are included; thus, the number of experiences (or lack of them, as in this case) is not an indication of the problems or frequency of spillage.

11 ANALYTICAL METHODS

The general approach adopted for each of the Priority Chemicals is as follows.

Methods have been documented here for analyses of samples from air, water and soil in a normally equipped chemical laboratory remote from the spill site. Customary sources of standard or recommended analytical methods were consulted, and outlines are presented for each chemical. These sources included publications of the U.S. National Institute for Occupational Safety and Health (NIOSH), the U.S. Environmental Protection Agency (EPA), the American Water Works Association (AWWA), the American Society for Testing and Materials (ASTM), and the American National Standards Institute (ANSI).

If the standard or recommended methods were judged to be reliable and specific enough for the analysis of environmental and materials samples from spill sites and if they do not require highly specialized laboratory equipment, no additional methods were sought.

If especially simple, reliable tests (e.g., commonly used industrial methods) were found, they have been presented as well.

11.1 Quantitative Method for the Detection of Calcium Chloride Particulates in Air

11.1.1 Atomic Absorption (NIOSH 1977). Calcium chloride particulates may be determined by atomic absorption spectroscopy using the method NIOSH recommends for calcium oxide. A range of 2.6 to 10.16 mg/m^3 (0.57 to 2.24 ppm) may be determined in air.

A known volume of air is drawn through a three-piece cassette filter holder capable of holding 37 mm filters. The filters are 0.8 mm cellulose-ester membrane. A sample volume of 85 L is recommended at a flow rate of 1.5 L/min.

The sample is transferred to a beaker and treated with 5 mL of concentrated nitric acid, heated on a hot plate (140°C) with a glass cover until most of the acid has evaporated. This step must be conducted in a fume hood. A 2 mL volume of concentrated nitric acid is added as well as 1 mL of 60 percent perchloric acid and the beaker covered with a glass cover. The sample is then heated until dense fumes of perchloric acid appear. Distilled water is used to rinse the sides of the beaker and the solution is evaporated to dryness. The sample is allowed to cool and the residue dissolved in 5 mL dilute (5.0 percent v/v) hydrochloric acid containing 1 percent lanthanum. The solution is quantitatively transferred to a 100 mL volumetric flask and two 5 mL rinsings of the beaker are also added to the flask. The volume is then taken to 100 mL with dilute hydrochloric acid solution containing 1.0 percent lanthanum. The sample is aspirated into an oxidizing air-acetylene flame. The absorbance at a wavelength of 422.7 nm is recorded using a suitable atomic absorption spectrophotometer. The calcium chloride is determined using a calibration curve.

11.2 Quantitative Method for the Detection of Calcium Chloride in Water

11.2.1 Atomic Absorption Spectroscopy (ASTM 1979). A range of 0.3 to 15 mg/L (ppm) of calcium in water may be determined using atomic absorption spectroscopy.

At least 2 L of water are collected in an appropriate container. The sample should be filtered prior to aspiration into an atomic absorption spectrophotometer, if particulate matter is present.

A 100 mL volume of sample is mixed with 25 mL of 5.0 percent lanthanum solution prior to aspiration. The sample is aspirated into an air-acetylene flame at a wavelength of 422.7 nm and the absorbance recorded using a suitable atomic absorption spectrophotometer. The calcium is determined using absorbance values and a standard curve.

11.3 Qualitative Method for the Detection of Calcium Chloride in Water

The sample is collected as in Section 11.2.1. A clean platinum wire is dipped in the sample and the wire is held at the hottest part of a nonluminous bunsen burner flame. A brick-red flame indicates the presence of calcium. This test is not specific for calcium chloride (Welcher 1955).

11.4 Quantitative Method for the Detection of Calcium Chloride in Soil

11.4.1 Colourimetric (Hesse 1972). A maximum of 25 µg of calcium in soil can be determined in a 1.0 g soil sample using colourimetry.

A 10 g sample of 0.15 mm, oven dried, soil is placed in a 250 mL beaker and 20 mL of concentrated nitric acid are added. The beaker is covered and carefully heated to oxidize the organic matter. A 10 mL volume of 60 percent perchloric acid is added and the mixture digested until dense fumes of perchloric acid appear. This procedure must be conducted in a fume hood. The sides of the beaker are washed with 60 percent perchloric acid as necessary. The mixture is then evaporated until all excess of perchloric acid is gone.

A suitable aliquot of the soil extract is taken and transferred to a test tube. The aliquot is diluted to 10 mL with water. A 10 mL volume of absolute methanol is added as well as 1 mL of buffer solution. This is prepared by dissolving 0.20 g sodium diethyl-dithiocarbamate in 100 mL of stock buffer solution. The stock buffer solution is prepared by dissolving 5.28 g of sodium tetraborate in 800 mL water and adding 10 g of sodium hydroxide. The mixture is allowed to cool then diluted to 1 L with water and stored in a polyethylene bottle. The pH of the buffer solution should be 12 and should be adjusted if necessary. To the sample is added 0.5 mL reagent solution prepared by dissolving 0.150 g glyoxal bis (2-hydroxyanil) in 30 mL of absolute methanol. The colour is developed for 25 minutes and the absorbance read on a suitable spectrophotometer at a wavelength of 535 nm. The calcium is determined using absorbance values and a standard curve.

11.5 Qualitative Method for the Detection of Calcium Chloride in Soil

The sample is collected as in Section 11.4.1 and the acid digestion procedure followed. A clean platinum wire is dipped in the sample and a few drops of 6 M hydrochloric acid are added. The platinum wire is held in the hottest part of a non-luminous bunsen burner flame. A brick-red flame indicates the presence of calcium. This test is not specific for calcium chloride (Welcher 1955).

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EnviroTIPS

Common Abbreviations

BOD	biological oxygen demand
b.p.	boiling point
CC	closed cup
cm	centimetre
CMD	count median diameter
COD	chemical oxygen demand
conc.	concentration
c.t.	critical temperature
eV	electron volt
g	gram
ha	hectare
Hg	mercury
IDLH	immediately dangerous to life and health
Imp. gal.	imperial gallon
in.	inch
J	joule
kg	kilogram
kJ	kilojoule
km	kilometre
kPa	kilopascal
kt	kilotonne
L	litre
lb.	pound
LC_{50}	lethal concentration fifty
LC_{LO}	lethal concentration low
LD_{50}	lethal dose fifty
LD_{LO}	lethal dose low
LEL	lower explosive limit
LFL	lower flammability limit
m	metre
m	meta
M	molar
MAC	maximum acceptable concentration
max	maximum
mg	milligram
MIC	maximum immision concentration
min	minute or minimum
mm	millimetre
MMAD	mass median aerodynamic diameter
MMD	mass median diameter
m.p.	melting point
MW	molecular weight
N	newton
NAS	National Academy of Sciences
NFPA	National Fire Protection Association
NIOSH	National Institute for Occupational Safety and Health
nm	nanometre
o	ortho
OC	open cup
p	para
P_c	critical pressure
PEL	permissible exposure level
pH	measure of acidity/alkalinity
ppb	parts per billion
ppm	parts per million
P_s	standard pressure
psi	pounds per square inch
s	second
STEL	short-term exposure limit
STIL	short-term inhalation limit
T_c	critical temperature
TC_{LO}	toxic concentration low
T_d	decomposition temperature
TD_{LO}	toxic dose low
TL_m	median tolerance limit
TLV	Threshold Limit Value
T_s	standard temperature
TWA	time weighted average
UEL	upper explosive limit
UFL	upper flammability limit
VMD	volume mean diameter
v/v	volume per volume
w/w	weight per weight
µg	microgram
µm	micrometre
°Be	degrees Baumé (density)