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FIELD EVALUATION OF A METHOD TO DETECT ACROLEIN IN IRRIGATION CANALS

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16. ABSTRACT

A method for quantitatively determining levels of acrolein when used as a herbicide to suppress aquatic weed growth in irrigation distribution systems was field evaluated on the Columbia Basin Project during the summer of 1972. Samples of treated irrigation water were taken, ice cooled, and examined by fluorometric analysis during the same day. Standards were prepared using untreated irrigation water taken from above the herbicide application points of the canals being studied. Acrolein application concentrations ranged between 0.1 to 2.0 ppm. Water samples were taken from canal segments as long as 64.5 miles, and acrolein concentrations as low as 0.02 ppm were detected.

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FIELD EVALUATION OF A METHOD TO DETECT ACROLEIN IN IRRIGATION CANALS

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June 1974

UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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The cooperation of personnel of the Irrigation Districts of the Columbia Basin Project is appreciated.

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INTRODUCTION

The Bureau of Reclamation has constructed extensive irrigation distribution systems on many of its projects to provide irrigation water to farmland. The efficient operation of many of the canals and laterals on these systems is adversely affected by heavy aquatic weed and algae growth, which impedes water flow, clogs pumping equipment, and requires extensive cleaning operations.

Submersed aquatic weeds and algae can be controlled quickly and effectively by acrolein applications. Since 1956, hundreds of field trials have been conducted in the United States and elsewhere with acrolein in cooperation with public and private agencies,[1]* demonstrating that this material is very effective in both irrigation canals and drainage ditches.

Acrolein is a water-soluble formulation containing 92 percent acrolein (CH_2=CH-CHO) as the principal constituent. It functions as a general cell toxicant and kills through its sulphydryl activity which destroys vital enzyme systems in the plant cell. The dead plant tissues gradually disintegrate and float downstream, thus no large masses of vegetation are released to clog canal structures.

Numerous phytotoxicity studies have been conducted in which treated water has been applied to crops by furrow, flood, or sprinkler irrigation.[1] Where toxicity has occurred, it has resulted from actual contact of the crop with the solution, as in flood irrigation. Toxicity may also occur by vapor action. Field observations and laboratory data show that fish vary considerably in their tolerance to acrolein. Carp and threadfin shad are particularly sensitive to acrolein. In general, fish are sensitive to concentrations presently used for weed control.

The Bureau of Reclamation, with the cooperation of the Agricultural Research Service and the Shell Chemical Company, conducted its first large canal field trials on acrolein on the Columbia Basin Project during fiscal year 1963.[2] The objectives of this study were: (1) development of a long-period, low-level application technique which substantially reduces weed growth; (2) reduction in the annual cost of weed control in large canals; (3) reduction of the potential of pollution of irrigation waters which may have other downstream uses before the herbicide disappears. The results of these initial field trials and others were quite favorable, prompting the Irrigation Districts on the Columbia Basin Project and elsewhere to begin using this method to suppress aquatic weed growth.

Data obtained from earlier attempts to quantitatively determine residual acrolein in irrigation water indicated that an improved methodology would be desirable. A published analytical procedure[3] was modified and developed. The methodology and techniques presented in this report were tested in a field study during the summer of 1972. The field study included herbicide applications, sampling, analysis, and evaluation. The results of this evaluation were encouraging.

SUMMARY

A fluorometric analytical procedure for acrolein determinations was evaluated and modified specifically for irrigation waters by the E&R Center Chemistry Laboratory and was field tested on the Columbia Basin Project. Standards prepared from the untreated water taken just above the canal segments treated provided linear fluorometer calibration curves for concentrations ranging from 0.004 ppm to 2.0 ppm. Higher concentrations could be determined, but the determination was unnecessary for the levels encountered in this study. This analytical method is adaptable to field conditions. It can be utilized best by locating the equipment in a minimum laboratory facility in the treatment area so that the sampling and analysis can be completed the same day.

Short time (4.6 to 5 hours) – high concentration (1.0 to 1.7 ppm) and long time (44 to 48 hours) – low concentration (0.1 to 0.16 ppm) applications were made to the canal segments examined. Treated canal segments as long as 64.5 miles were sampled and acrolein concentrations as low as 0.02 ppm were detected.

APPLICATIONS

Application concentrations of acrolein discussed under the section "Results and Discussion" of this report and presented in the tables therein were sufficient for satisfactory aquatic weed suppression.

A reliable analytical procedure is important to monitoring the levels of acrolein in the water throughout the canal as well as in return flows.

The revised analytical method is a much improved method over those used heretofore, especially at the

*Numbers designate references at the end of the text. Suggested Water Measurement references are given in Appendix I.

very low levels. This method has been adopted for future use by the Bureau as a usable analytical method for field analysis of acrolein in water.

MATERIALS AND METHODS

Herbicide Application in Flowing Water

Acrolein is chemically highly reactive, flammable, and a lachrymator, so the method by which it is applied to the canal has been designed to provide safe and easy handling. The equipment and techniques described provide accurate metering and control of the product application for prolonged periods with minimum exposure to those handling the material.

The amount of acrolein required is primarily determined by the amount of water flow in the stream, although water temperature, velocity, and weed density must also be considered. Streamflow is generally stated in cubic feet per second and the amount of material used is expressed in terms of this value, see Appendix I.

Since acrolein is normally supplied in pressure cylinders packaged under a low-pressure blanket of inert oxygen-free nitrogen, it can be metered and injected directly into the canal.

The herbicide is added over a time interval forming a segment or wave of treated water that moves downstream, bathing the weeds in toxicant. The effectiveness of the acrolein is directly related to its concentration in the water and the time of application. Thus the effectiveness of the treatment is measured by the product of concentration and time.

The herbicide is dissipated as the blanket of treated water moves downstream through absorption by the weed tissue and vapor loss. Therefore, in long canals it may be necessary to "reinforce the wave" at points downstream from the first application. This is commonly referred to as a "booster" application.

Sample Collection

Untreated irrigation water obtained immediately above the site of herbicide application is used for standards and blank (background) determinations. After ample distance is allowed for thorough mixing downstream (approximately 1/2 to 1 mile), triplicate samples are taken. The samples are placed in an ice-cooled container and analyzed later the same day. For detailed information on the analytical method, see Appendix II.

RESULTS AND DISCUSSION

Application Considerations

It has been recommended that the maximum concentration for acrolein should not exceed 15 ppm in canal applications, but the maximum concentration applied in canals investigated for this report was approximately 2 ppm. Acrolein concentrations routinely used on the Columbia Basin Project irrigation districts are in the 0.1 ppm or 1- to 2-ppm range. The low-level concentration is applied for long time durations, Table 1, and the higher concentrations are applied for relatively short

Table 1

HERBICIDE APPLICATION DATA FOR LOW-CONCENTRATION ACROLEIN TREATMENTS SAMPLED ON TWO LONG-DISTANCE CANAL SEGMENTS

		A	B	C	D			
Canal	Date application started	Gallons herbicide applied	Time elapsed for application (hours)	Flow capacity (cfs)	Intended application concentration (ppm)	Date canal sampled	Length of canal segment sampled (miles)	Number of samples taken
Potholes	7-19-72	350	48	1640	0.16	7-20-72	35	11
Potholes booster*	7-19-72	270	44	1200	0.16	7-20-72	**22.5	**6
East Low	9-28-72	234	48	1400	0.10	9-29-72	64.5	14

*Booster application was made 12.5-13 miles downstream from initial application.
**These data apply to samples and canal segment downstream from booster application.

time periods, Table 2. Satisfactory weed suppression is obtained using these concentrations and application periods.

Analytical Check of Intended Application Concentration

Tables 3 and 4 give a comparison between the intended application concentration and that amount actually present as determined at the nearest sampling station downstream. All herbicide applications were made by Irrigation District personnel, and all data relating to an application such as gallonage, cubic feet per second, time, and intended concentration were provided by them. Since the first sampling station is between 0.5 to 1 mile of the application site, a slight deviation (± 0.02 ppm) from the intended concentration is normal, and the analysis provides a check on the application rate.

Booster Check and Long-distance Sampling

Table 3 provides other information of interest. Table 1 notes that a "booster" application is made in the Potholes Canal at 12.5 to 13 miles downstream from the initial application. This "boost" was detected in the analysis results from samples taken at the 13.5-mile station. Results in Table 3 for the Potholes and East Low Canals also confirmed the presence of detectable levels of herbicide from the 0.1 ppm "nonboosted" application at distances of 35 and 64.5 miles downstream.

Application Irregularities

In Table 4, it is noted that there were irregularities in the Royal Branch Canal application. Analyses from the initial sampling station give acrolein values considerably higher than the intended application concentration, which is the exact opposite from the usual observation – that of slightly higher or lower values. Both information regarding application irregularities provided by Irrigation District personnel, and the review of the analysis results show that applicator malfunction or application error was present.

Standardization for Fluorometric Method

Figure 1 is a graph of acrolein herbicide standards made from two irrigation canal waters and distilled water. The concentration range depicted encompasses most of the application and sample ranges in this study. Linearity is also observed in standard curves of considerably higher concentrations. The curves of each canal prepared for these low acrolein concentrations are significantly nonparallel with respect to each other, necessitating preparation of individual canal curves. Curves for considerably higher concentrations would employ a less sensitive scale setting on the fluorometer, minimizing the "background" effects which alter the low-range curve slopes.

CONCLUSIONS

The results of the field evaluation of the modified fluorometric method for analysis of acrolein in irrigation water shows the method to be very practical and easy to use in the field. The data to support the field study of the efficacy of low levels of acrolein were obtained rapidly and conveniently. Analysis in the field provided convenient preliminary review of experimental data and any necessary adjustments could be made readily.

REFERENCES

1. *Aqualin Herbicide Process Handbook, Revision 1*, Shell Chemical Company, U.S. Patent No. 2,959,476; 1965

2. *Progress Report – Acrolein on Large Canals*, Bureau of Reclamation, Columbia Basin Project, Ephrata, Washington, August 1963

3. Alarcon, R. A., "Fluorometric Determination of Acrolein and Related Compounds with m-Aminophenol," *Anal. Chem.* 40, 1704 (1968).

Table 2

HERBICIDE APPLICATION DATA FOR HIGH-CONCENTRATION ACROLEIN TREATMENTS SAMPLED ON THREE SHORT-DISTANCE CANAL SEGMENTS

Canal	Date application started	A: Gallons herbicide applied	B: Time elapsed for application (hours)	C: Flow capacity (cfs)	D: Intended application concentration (ppm)	Date canal sampled	Length of canal segment sampled (miles)	Number of samples taken
West	7-21-72	106	5	535	1.15	7-21-72	7	5
Royal Branch	8-1-72	106	4.66	417	1.70	8-1-72	7	5
West	8-10-72	106	4.83	560	1.25	8-10-72	6.3	5

Table 3

ACROLEIN CONCENTRATION IN WATER SAMPLES FROM 48-HOUR LOW-CONCENTRATION TREATMENT OF CANALS

Canal	Date sample taken and analyzed	Sampling point (miles below initial application)	Acrolein average (ppm)
Potholes	7-20-72	1.0	0.14
		2.5	0.13
(Intended application		5.0	0.10
concentration: 0.14 ppm)		10.0	0.10
		12.5	0.09
		13.5	0.20
Booster application at		15.0	0.18
mile 12.65		20.0	0.15
		25.0	0.13
		30.0	0.08
		35.0	0.05
East Low	9-29-72	0.5	.08
		1.0	.09
(Intended application		2.5	.07
concentration: 0.11 ppm)		5.0	.10
		7.5	.10
		10.0	.10
		15.0	.08
		20.0	.08
		30.0	.06
		40.0	.02
		41.0	.03
		48.0	.02
		59.0	.03
		64.5	.03

Table 4

ACROLEIN CONCENTRATION IN WATER SAMPLES FROM HIGH-CONCENTRATION SHORT-TIME TREATMENT OF CANALS

Canal	Date sample taken and analyzed	Sampling point (miles below initial application)	Acrolein average (ppm)
West	7-21-72	1.0	1.13
		2.5	1.01
(Intended application		4.0	0.92
concentration: 1.24 ppm)		5.5	0.82
		7.0	0.69
Royal Branch	8-1-72	1.0	2.16
		2.5	2.07
(Intended application		4.0	1.78
concentration: *1.70 ppm)		**5.5	0.0
		**7.0	0.0
West	8-10-72	1.0	1.08
		2.5	1.02
(Intended application		4.0	0.88
concentration: 1.25 ppm)		5.5	0.91
		6.3	0.89

*There were some irregularities in this application causing a higher concentration as noted in the acrolein found in water samples.
**Samples at these two stations were evidently taken before the acrolein treated water arrived.

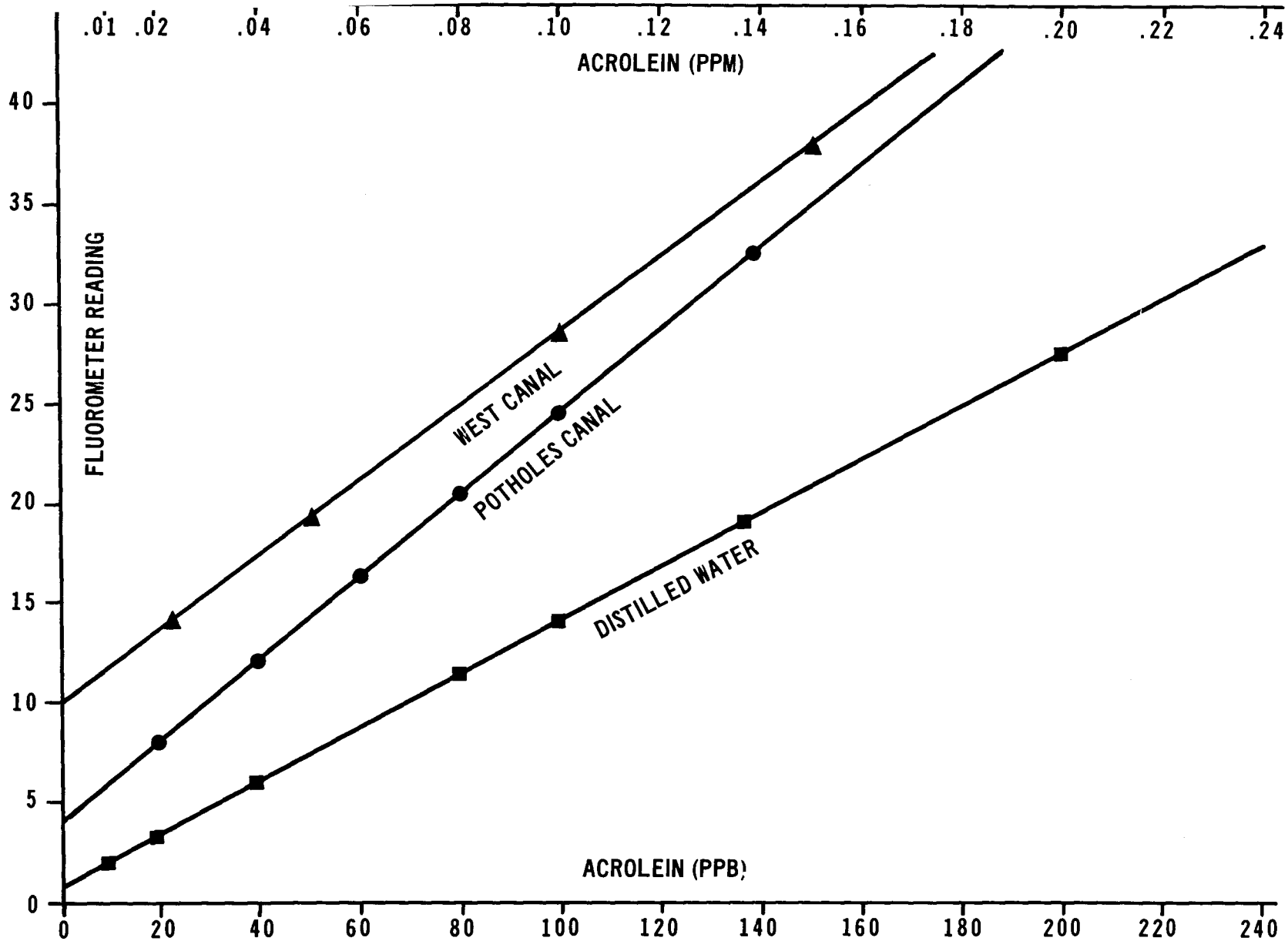

Figure 1. Acrolein standards made from canal and distilled water.

APPENDIX I

ACROLEIN CONCENTRATION TABLE
Flowing Water

Application time	Concentration (in ppm) at 1 gal/cfs	at 2 gals/cfs	at 3 gals/cfs
1 minute	1,884.0	3,768.0	5,652.0
30 minutes	62.8	125.6	188.4
1 hour	31.4	62.8	94.2
1.5 hours	20.9	41.9	62.8
2 hours	15.7	31.4	47.1
4 hours	7.9	15.7	23.6
6 hours	5.2	10.5	15.7
8 hours	3.9	7.9	11.8
10 hours	3.1	6.3	9.4
12 hours	2.6	5.2	7.9
24 hours	1.3	2.6	3.9
36 hours	0.87	1.7	2.6
48 hours	0.68	1.4	2.0

$$\frac{\text{Dosage (gallons/cfs)} \times 1.884}{\text{Application time (minutes)}} = \text{ppm (acrolein herbicide concentration)}$$

SUGGESTED WATER MEASUREMENT REFERENCES

"Water Measurement Manual," U.S.D.I., Bureau of Reclamation, Denver, Colorado, May 1953

"An Irrigation Guide for Colorado," Bulletin 432-A, April 1954, Colorado Agricultural and Mechanical College, Fort Collins

"Measuring Irrigation Water," Bulletin 448-A, Colorado State University, Fort Collins

APPENDIX II
MODIFIED FLUOROMETRIC ANALYTICAL METHOD FOR ACROLEIN

The method presented here is a modification for irrigation water analysis of the fluorometric determination of acrolein by Alarcon.[3] A Turner Model III Portable Fluorometer was used.

PROCEDURE FOR FLUOROMETRIC ACROLEIN ANALYSIS IN IRRIGATION WATER

Method Modification by D. M. Hopkins
With Turner Model 111 Fluorometer

A. **Preparation of Mixed Reagent**

1. 500 mg m-aminophenol

2. 600 mg hydroxylamine hydrochloride

3. Dissolve in 50 ml 1N HCL

Good for 3 or 4 days if stored at room temperature away from direct light.

B. **Preparation of "Spiked" Field Water Standards**

1. Tare a 5- or 10-ml stoppered volumetric flask containing approximately 2-ml untreated irrigation water.

2. Into the tared flask, deliver 0.5-ml acrolein from a syringe of the same or larger capacity (stopper immediately).

3. Immediately weigh the flask containing the acrolein and calculate the actual amount of acrolein added. (This weight determines the remaining standard concentrations.)

4. Fill the acrolein-containing flask roughly to the mark with untreated irrigation water, taking care not to leave the stopper off very long.

5. Add contents of volumetric flask into a 500-ml volumetric flask half filled with untreated irrigation water; stopper immediately, swirl, then fill *accurately* to the mark with untreated irrigation water. This solution should have an acrolein concentration of approximately 1,000 ppm or 1 ml = 1 mg of acrolein.

6. A series of standards can now be prepared from this stock solution.*

   a. For example, 1 ml of a stock solution (1 mg/ml) prepared as in No. 5 diluted to 500 ml will give a solution of *2 ppm* concentration. 1 ml of this solution diluted to 500 ml gives 4×10^{-3} (0.004) ppm or 4 ug/1 (4 ppb) solution. This concentration is sufficient for the minimum standard in the analysis procedure. Using the 2-ppm solution as the working stock, higher concentration standards can be prepared by choosing the appropriate pipette volume and diluting to volumes of 250 or 500 ml. A maximum standard concentration of 0.5 ppm (500 ppb) is usually sufficient for most sample concentration ranges.

C. **Treatment of Samples and Standards with Reagents**

1. Into a 10-ml test tube pipette place 4 ml of the standard and/or sample. A 4-ml aliquot of distilled water should also be used for the reagent blank.

2. Then 1 ml of 5N HCL is added to each test tube and the contents stirred with a glass stirring rod. Add 1 ml of the mixed reagent and then stir contents until completely miscible. Leave glass rods in test tubes.

3. Use test tube holders to grasp tubes near their tops and place tubes in plastic tube holder, which is resting on a 600-ml beaker containing boiling water. Heat samples and/or standards for 10 minutes in this water bath device.

4. After the 10 minutes of heating, pick up the plastic test tube holder containing the samples and place it on another 600-ml breaker containing water at room temperature, or a little cooler, so that the samples can be rapidly cooled to room temperature.

5. After cooling, fill quartz fluorometer cuvettes with sample. Read the standards and/or samples adjusting the zero concentration on the fluorometer to correspond to the reagent blank. Plot the standard curve and determine sample values.

D. **Instrument Accessories**

1. Primary Filter: Turner No. 110-810 (7-54)

*Note: All standards are prepared with untreated irrigation water.

2. Secondary Filter: Turner No. 110-825 (65A)

a. A neutral density (ND) 10-percent filter is desirable with the 65A secondary filter.

3. The Turner high-sensitivity door and sample compartment are employed.

4. A far UV exciting lamp.

E. **Acid, HCL, Solutions**

1N HCL: 120-gms concentrated HCL diluted to 1 liter

(60-gms concentrated HCL diluted to 500 ml, etc.)

7-1750 (3-71)
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CONVERSION FACTORS—BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg, that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Inches	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*0.0040469	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*1,233,500	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
Short tons (2,000 lb)	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
Pounds per cubic foot	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
Feet per second	0.3048 (exactly)*	Meters per second
Feet per year	$*0.965873 \times 10^{-6}$	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	*0.3048	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	*0.028317	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	*0.453592	Kilograms
Pounds	*4.4482	Newtons
Pounds	$*4.4482 \times 10^5$	Dynes

Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories
British thermal units (Btu)	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	*1.35582	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*0.09290	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor) transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	*304.8	Liters per square meter per day
Pound-seconds per square foot (viscosity)	*4.8824	Kilogram second per square meter
Square feet per second (viscosity)	*0.092903	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	*35.3147	Millicuries per cubic meter
Milliamps per square foot	*10.7639	Milliamps per square meter
Gallons per square yard	*4.527219	Liters per square meter
Pounds per inch	*0.17858	Kilograms per centimeter

GPO 854-897

ABSTRACT

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