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JUL 11 2008

STATE OF ILLINOIS
Pollution Control Board

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	R08-18
PROPOSED AMENDMENTS TO	)	(Rulemaking-Public Water Supplies)
GROUNDWATER QUALITY	)	
STANDARDS	)	
(35 Ill. Adm. Code 620)	)	
	)	

NOTICE OF FILING

Dorothy Gunn, Clerk
Illinois Pollution Control Board
James R. Thompson Center
100 W. Randolph, Suite 11-500
Chicago, Illinois 60601
(Via Federal Express)

Bill Richardson
Chief Legal Counsel
Illinois Dept. of Natural Resources
One Natural Resources Way
Springfield, Illinois 62702-1271
(Via First Class Mail)

Matt Dunn
Environmental Bureau Chief
Office of the Attorney General
James R. Thompson Center
100 W. Randolph, 12th Floor
Chicago, Illinois 60601
(Via First Class Mail)

Richard R. McGill, Jr.
Hearing Officer
Illinois Pollution Control Board
James R. Thompson Center
100 W. Randolph, Suite 11-500
Chicago, Illinois 60601
(Via Federal Express)

(Service List-Via First Class Mail)

PLEASE TAKE NOTICE that I have today filed with the Office of the Clerk of the Illinois Pollution Control Board the Illinois Environmental Protection Agency's MOTION TO CORRECT THE TRANSCRIPT, ERRATA SHEET NUMBER 3, AND SUPPLEMENTAL TESTIMONY OF THE ILLINOIS EPA a copy of each of which is herewith served upon you.

ILLINOIS EVIRONMENTAL
PROTECTION AGENCY

By: Kimberly A. Geving

Kimberly A. Geving
Assistant Counsel
Division of Legal Counsel

DATED: July 10, 2008

1021 North Grand Ave. East
P.O. Box 19276
Springfield, Illinois 62794-9276
(217) 782-5544

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IN THE MATTER OF:)
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STANDARDS)
(35 Ill. Adm. Code 620))
)

R08-18
(Rulemaking-Public Water Supplies)

MOTION TO CORRECT THE TRANSCRIPT

NOW COMES the Illinois Environmental Protection Agency ("Illinois EPA") by one of its attorneys, Kimberly A. Geving, and pursuant to 35 Ill. Adm. Code 101.604 moves the hearing officer in this matter to correct the transcript of June 18, 2008 as follows:

Page	Line	Correction
10	4	Change "Standard" to "Standards"
10	12-13	Change "upgraded subject to" to "updated for"
10	23	Change "RECRA" to "RCRA"
11	11	Change "incorporation" to "incorporations"
11	13	Change "changes" to "references"
13	1	Change "contaminant" to "contaminants"
14	6	Change "Innovated" to "Integrated"
14	14	Same change as in line 6 on this page
15	2	Change "Review" to "Reviewed"
15	14	Change "stop" to "stopped"
15	22	Add and "and" after "Substances"
16	5	Change "bioda" to "biota"
16	13	Change "Tier" to "Tiered"
17	18	Change "self" to "soil"
19	21	Mr. Davis' first name is Alec, not Alex
24	21	Change "R89149(b)" to "R89-14(B)"
27	8	Change "35IlAd.620.410(e)" to "35 Ill. Adm. Code 620.410(e)"
28	14	Change "mailable" to "malleable"
28	17	Delete "proposed and then"
28	18	After "of" add "cations and anions"
28	18	Replace "already put the" with "are composed of"
28	18	Make the last "cation" plural

28	19	Make “anion” plural
28	21	Delete “and those”
31	9	The reference to “THE COURT” is incorrect
31	9	The reference to “Dave” is incorrect. There was no Dave present at the hearing
32	5	Change “instigation” to “removal efficiency of”
32	17	Change “not” to “none”
34	6	Change “carcinogenic” to “carcinogen”
34	13	Change “620.10(b)” to “620.410(b)”
36	23	Change “043” to “.043”
37	24	Change “Qualities” to “Quality’s”
40	2	Change “contents” to “constants”
40	12	Change “rule” to “Board”
41	23	Change “R8914(b)” to “R89-14(B)”
42	3	Change “basis” to “bases”
42	14	Change “to” to “and”
42	14	Change “confirm” to “confirmed”
42	14	Replace “by the” with “in”
43	21	Change “35Il.Ad.611” to “35 Ill. Adm. Code 611”
51	2	Change “mount” to “melt”
51	3	Change “go” to “going”
51	19	Change “R914(b)” to “R89-14(B)”
51	24	We believe the hearing officer said “R08-18”
56	20	Add “addition” after “in”
58	19	Change “prescribes” to “subscribes”
62	18	Change “1-dichloroethane” to “1,1-dichloroethane”

Respectfully submitted,

ILLINOIS ENVIRONMENTAL
PROTECTION AGENCY

By: Kimberly A Geving
Kimberly A. Geving
Assistant Counsel
Division of Legal Counsel

Dated: July 10, 2008

1021 N. Grand Ave. East
P.O. Box 19276
Springfield, Illinois 62794-9276
(217) 782-5544

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:)
)
PROPOSED AMENDMENTS TO) R08-18
GROUNDWATER QUALITY) (Rulemaking-Public Water Supplies)
STANDARDS)
(35 Ill. Adm. Code 620))
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ERRATA SHEET NUMBER 3

NOW COMES the Illinois Environmental Protection Agency through one of its attorneys, Kimberly Geving, and submits this ERRATA SHEET NUMBER 3 to the Illinois Pollution Control Board and the participants on the Service List. Please note that the errata changes reflect amendments to our original proposal as submitted to the Board on February 15, 2008 and not to the existing rule or any changes made in Errata Sheets 1 and 2.

Tom Hornshaw, Rick Cobb, and Gary King will provide testimony in support of these changes at the hearing on July 16, 2008.

Section		
620.410(b)	Anthracene	2.1~~0.0434~~
	Chloroform	0.07 ~~0.0002~~
	Chrysene	0.012 ~~0.0016~~
	Di-n-octyl phthalate	0.28 ~~0.02~~
	Fluoranthene	0.28 ~~0.206~~
	Indeno(1,2,3-cd)pyrene	0.00043
620.420(b)	Anthracene	10.5 ~~0.0434~~
	Benzo(k)fluoranthene	0.006 ~~0.0008~~
	Benzo(a)pyrene	0.002 ~~0.00162~~
	Chloroform	0.35 ~~0.001~~
	Chrysene	0.06 ~~0.0016~~
	Di-n-octyl phthalate	1.4 ~~0.02~~
	Fluoranthene	1.4 ~~0.206~~
	Indeno(1,2,3-cd)pyrene	0.0022 ~~0.00043~~
	Methoxychlor	0.2

620.605(c) Remove this from the proposal.

Respectfully submitted,

ILLINOIS ENVIRONMENTAL
PROTECTION AGENCY

By: Kimberly A Geving
Kimberly A. Geving
Assistant Counsel
Division of Legal Counsel

DATED: July 10, 2008

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P.O. Box 19276
Springfield, Illinois 62794-9276
(217) 782-5544

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:)
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GROUNDWATER QUALITY) R08-018
STANDARDS) (Rulemaking-Public Water Supplies)
(35 Ill. Adm. Code 620))
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SUPPLEMENTAL TESTIMONY OF THE ILLINOIS EPA

This testimony responds to additional questions and requests provided in an Illinois Pollution Control Board Hearing Officer Order issued on June 20, 2008. The testimony is intended to answer the following questions asked in the Illinois Pollution Control Board ("Board") Hearing Officer Order. Additionally, the Illinois EPA is adding Gary King to the panel of witnesses, and this supplemental testimony is a joint effort of Richard P. Cobb, Thomas C. Hornshaw, and Gary King. All three witnesses will be available to answer questions regarding this written testimony.

I. BOARD QUESTIONS/REQUESTS AND ILLINOIS EPA RESPONSES

Board questions/requests are followed by emboldened Illinois EPA responses.

Question 1 - At page 11 of Mr. Cobb's pre-filed testimony, he states that the proposed standards are based on a United States Environmental Protection Agency ("USEPA") Maximum Contaminant Level ("MCL") or Board MCL, a reference dose ("RfD") in USEPA's Integrated Risk Information System (IRIS), USEPA Health Effects Assessment Summary Table ("HEAST") RfD, Provisional Peer Reviewed Toxicity Values ("PPRTV") RfD, and IRIS Slope Factor ("Sfo").

a. Please clarify whether USEPA's MCLs are the same as the Board's MCLs. If not, please explain any differences.

b. The proposed standards for several inorganic and organic chemical constituents are based on RfDs and Sfos obtained from the various USEPA databases. Please explain how the Agency used the RfDs and Sfos to derive the proposed standards for various chemical constituents

    i. Would the Agency be able to update the tables on pages 12 and 13 of Mr. Cobb's pre-filed testimony to include the appropriate RfD values used to determine the proposed standards?

ii. Also, would the Agency be able to submit pertinent documentation from the USEPA databases concerning the RfDs and Sfos used to derive the proposed standards?

c. Please clarify whether any of the proposed Class I standards are based on the RfDs from USEPA's HEAST database. If so, please submit documentation concerning the relevant RfDs/Sfos used to derive the proposed standards.

<u>Response to Question (1)(a)</u> – **Yes. The U.S. EPA MCL is the same as the Board's drinking water standards at 35 Ill. Adm. Code 611.**

<u>Response to Request (1)(b)(i) and (1)(b)(ii) and (1)(c)</u> – **In response to these requests, we reviewed the basis for all the proposed changes to the groundwater standards. The accompanying Table 1 (below) lists the basis for each change. This review has resulted in a few additional changes to the proposed standards, which are explained as follows:**

- **Chloroform- The values originally proposed, 0.0002 mg/l for Class I and 0.001 mg/l for Class II, were from the TACO groundwater objectives. These values were developed from the lowest PQL, the only option for developing a Health Advisory concentration for a carcinogen pursuant to Subpart F at the time this chemical was entered into TACO. However, our review found both a cancer Sfo (from California EPA) and a non-cancer RfD (from IRIS), and since we are proposing to amend the Subpart F procedures for carcinogens to also consider the 1-in-1,000,000 cancer risk level, we now need to compare the 1-in-1,000,000 risk (0.0027 mg/l) and PQL (0.0002 mg/l) values as potential groundwater standards. Also, the IRIS RfD has been used by EPA as the basis for promulgating a final Maximum Contaminant Level Goal (MCLG) of 0.07 mg/l in the Stage 2 Disinfectants and Disinfectants Byproducts Rule, which they state as being protective for both cancer and non-cancer effects. This information presents a dilemma in that Subpart F, while specifying procedures for developing Health Advisories for carcinogens and non-carcinogens, does not provide guidance as to which takes precedence if both values can be developed. In most cases, we would recommend the lower of the two, but in this case we prefer the MCLG, even though it is the higher of the two values (0.07 vs. 0.0027 mg/l), since it is taken from a promulgated federal rule and is found to be protective against cancer. We welcome the Board's review of this issue.**
- **Solubility- All references to the use of solubility as a basis for groundwater standards have been removed (discussed in depth in response to Request 8).**
- **Benzo(a)pyrene (BaP) and Methoxychlor- Our proposal calls for replacing the existing Class II groundwater standards for BaP (0.002 mg/l) and Methoxychlor (0.2 mg/l) with values based on solubility, but since solubility is no longer considered in developing standards, the proposed solubility-based standards of 0.0016 mg/l and 0.045 mg/l, respectively, should be dropped and these two chemicals should be removed from the proposal.**

Response to Question (1)(c)- The reference to HEAST should be dropped. HEAST was used to derive some of the TACO objectives. However, we are now listing the TACO objective as the basis for some of the proposed new groundwater standards.

TABLE 1: Toxicology Values Used To Develop Proposed 620 Standards

Inorganic Chemicals	Proposed Class I Standard (mg/L)	Basis for Class I Standard	Proposed Class II Standard (mg/L)	Basis for Class II Standard	Reference Dose (RfD)	Oral Slope Factor (SFo)
Arsenic*	0.010	Board and U.S.EPA MCL	0.20	Irrigation	-	-
Molybdenum	0.035	IRIS RfD	0.035	1X Class I	0.005	-
Perchlorate	0.0049	IRIS RfD	0.0049	Treatment Factor	0.0007	-
Vanadium	0.049	TACO/HEAST RfD	0.1	Irrigation	0.007	-

Volatile Organic Compounds	Proposed Class I Standard (mg/L)	Basis for Class I Standard	Proposed Class II Standard (mg/L)	Basis for Class II Standard	Reference Dose (RfD)	Oral Slope Factor (SFo)
Acetone	6.3	TACO/IRIS RfD	6.3	1X Class I	0.9	-
2-Butanone (MEK)	4.2	IRIS RfD	4.2	1X Class I	0.6	-
Carbon disulfide	0.7	TACO/IRIS RfD	3.5	5X Class I	0.1	-
Chloroform* (risk-based)	0.0027	10^{-6} cancer risk/CalEPA SFo	0.014	5X Class I	-	0.031
Chloroform* (criteria-based)	0.07	U.S.EPA MCLG	0.35	5X Class I	-	-
Dichlorodifluoromethane	1.4	IRIS RfD	7.0	5X Class I	0.2	-
1,1-Dichloroethane	1.4	PPRTV RfD	7.0	5X Class I	0.2	-
Isopropylbenzene (Cumene)	0.7	IRIS RfD	3.5	5X Class I	0.1	-
Trichlorofluoromethane	2.1	IRIS RfD	10.5	5X Class I	0.3	-

Semivolatile Organic Compounds	Proposed Class I Standard (mg/L)	Basis for Class I Standard	Proposed Class II Standard (mg/L)	Basis for Class II Standard	Reference Dose (RfD)	Oral Slope Factor (SFo)
Acenaphthene	0.42	TACO/IRIS RfD	2.1	5X Class I	0.06	-
Anthracene	2.1	TACO/IRIS RfD	10.5	5X Class I	0.3	-
Benzo(a)anthracene*	0.00013	TACO/ADL	0.00065	5X Class I	-	-
Benzo(b)fluoranthene*	0.00018	TACO/ADL	0.0009	5X Class I	-	-
Benzo(k)fluoranthene*	0.0012	10^{-6} cancer risk/IRIS SFo	0.006	5X Class I	-	0.073
Benzoic acid	28.0	TACO/IRIS RfD	28.0	1X Class I	4.0	-
Chrysene*	0.012	10^{-6} cancer	0.06	5X Class I	-	0.0073

		risk/IRIS SFo				
Dibenzo(a,h,)anthracene*	0.0003	TACO/ADL	0.0015	5X Class I	-	-
Diethyl phthalate	5.6	TACO/IRIS RfD	5.6	1X Class I	0.8	-

Semivolatile Organic Compounds (continued)	**Proposed Class I Standard (mg/L)**	**Basis for Class I Standard**	**Proposed Class I Standard (mg/L)**	**Basis for Class II Standard**	**Reference Dose (RfD)**	**Oral Slope Factor (SFo)**
Di-n-butyl phthalate	0.7	TACO/IRIS RfD	3.5	5X Class I	0.1	-
Di-n-octyl phthalate	0.28	TACO/ PPRTV RfD	1.4	5X Class I	0.04	-
Fluoranthene	0.28	TACO/IRIS RfD	1.4	5X Class I	0.04	-
Fluorene	0.28	TACO/IRIS RfD	1.4	5X Class I	0.04	-
Indeno(1,2,3-cd)pyrene*	0.00043	TACO/ADL	0.0022	5X Class I	-	-
2-Methylnaphthalene	0.028	IRIS RfD	0.14	5X Class I	0.004	-
2-Methylphenol	0.35	TACO/IRIS RfD	0.35	1X Class I	0.05	-
Naphthalene	0.14	TACO/IRIS RfD	0.22	TACO/IRIS RfD	0.02	-
p-Dioxane*	0.0077	10^{-6} cancer risk/IRIS SFo	0.0077	1X Class I	-	0.011
Pyrene	0.21	TACO/IRIS RfD	1.05	5X Class I	0.03	-

Pesticide Compounds	**Proposed Class I Standard (mg/L)**	**Basis for Class I Standard**	**Proposed Class II Standard (mg/L)**	**Basis for Class II Standard**	**Reference Dose (RfD)**	**Oral Slope Factor (SFo)**
alpha-BHC*	0.00011	TACO/ADL	0.00055	5X Class I	-	-
Dicamba	0.21	IRIS RfD	0.21	1X Class I	0.03	-
MCPP (Mecoprop)	0.007	IRIS RfD	0.035	5X Class I	0.001	-

Explosive Compounds	**Proposed Class I Standard (mg/L)**	**Basis for Class I Standard**	**Proposed Class II Standard (mg/L)**	**Basis for Class II Standard**	**Reference Dose (RfD)**	**Oral Slope Factor (SFo)**
1,3-Dinitrobenzene	0.0007	IRIS RfD	0.0007	1X Class I	0.0001	-
2,4-Dinitrotoluene*	0.0001	10^{-6} cancer risk/IRIS SFo	0.0001	1X Class I	-	0.68
2,6-Dinitrotoluene*	0.00031	TACO/ADL	0.00031	1X Class I	-	-
HMX	1.4	IRIS RfD	1.4	1X Class I	0.05	-
Nitrobenzene	0.0035	TACO/IRIS RfD	0.0035	1X Class I	0.0005	-
RDX	0.084	IRIS RfD	0.084	1X Class I	0.003	-
1,3,5-Trinitrobenzene	0.84	IRIS RfD	0.84	1X Class I	0.03	-
2,4,6-Trinitrotoluene	0.014	IRIS RfD	0.014	1X Class I	0.0005	-

* Denotes a carcinogen.

\- Denotes no data or not applicable.

Question 2 - On page 11 of Mr. Cobb's pre-filed testimony, he states that some of the proposed standards are based on Method Detection Limits ("MDLs") used to derive the Part 620, Subpart F, Appendix A: Human Threshold Toxicant Advisory Concentration for Tiered Approach to Corrective Action Objectives ("TACO") groundwater objectives under Part 742.

a. Please clarify whether all of the proposed standards based on TACO groundwater objectives are based on MDLs.

b. Also, please explain how MDLs were used to derive the proposed standards for which TACO groundwater objectives are listed as the basis for the standard.

Response to Question (2)(a) – Referencing the MDL was incorrect. The practical quantitation limit ("PQL") should have been referenced.

Response to Question (2)(b) - Some of the TACO objectives were based on PQLs (not MDLs) where the health based numbers were below the PQL.

Question 3 - Also on page 11 of Mr. Cobb's pre-filed testimony, he notes that carcinogens are denoted in the proposed Class I standard by an asterisk. Please clarify whether dibenzo(a,h)anthracene should be listed under Section 620.410(b) with an asterisk to indicate that it is a carcinogen.

Response to Question 3 – Dibenzo (a,h) anthracene is a carcinogen, and should be so noted.

Request 4 - The proposal lists the acronyms for several chemical constituents in Section 620.410. Please provide the chemical names for alpha-BHC, MCPP, HMX and RDX.

Response to Request 4 – The following provides the chemical, common and abbreviated names:

Chemical Name	Common Name	Abbreviated Name
1,2,3,4,5,6-hexachlorocyclohexane	**Alpha-Benzene hexachloride**	**alpha-BHC**
2-(2-Methyl-4-chlorophenoxy) propionic acid	**Mecoprop**	**MCPP**
Octahydro-1,3,5,7-Tetranitro-1,3,5,7-Tetrazocine	**High Melting Explosive, Octogen**	**HMX**
Hexahydro-1,3,5-trinitro-1,3,5-triazine	**Royal Demolition Explosive, Cyclonite**	**RDX**

Request 5 - On page 14 of Mr. Cobb's pre-filed testimony, he states that the proposed Class II standards for inorganic constituents are based on irrigation and livestock watering from a

1972 report published by the National Academy of Sciences entitled "Water Quality Criteria." Would the Agency be able to submit a copy of the NAS report or the relevant pages of the report?

<u>Response to Request</u> 5 – Per your request a copy of the NAS report is attached.

<u>Question 6</u> - On page 14 of Mr. Cobb's pre-filed testimony, the groundwater standards table lists the basis for the proposed Class II standard for molybdenum as the Class I standard, but it is also noted that the irrigation criterion is 10. Please explain the rationale for proposing the Class II standard for molybdenum at the same level as Class I standard instead of the irrigation criterion.

<u>Response to Question 6</u> – The note should have been that the irrigation criterion is 0.01 milligrams per liter ("mg/l"). Therefore, since the magnitude of the proposed Class I standard at 0.035 mg/l is not significantly different from 0.01 mg/l, the Illinois EPA proposed the 0.035 mg/l as the Class II standard.

<u>Question 7</u> - On page 16 of Mr. Cobb's pre-filed testimony, he states that a five-fold treatment factor was used to derive a Class II standard for organic compounds with a Koc value greater than that of ethylbenzene or a Henry's Law constant greater than that of methylene chloride. Please comment on whether the same factors were considered in deriving the TACO Class II groundwater objectives, which are also being proposed as the Class II standards in the Agency's proposal.

<u>Response to Question 7</u> – Yes.

<u>Request 8</u> - Mr. Cobb lists water solubility as the basis for several Class I and Class II standards. Please provide citations to the publications from which the Agency obtained the water solubility values to develop the standards.

<u>Response to Request 8</u> - There has been considerable dialogue recently between the Agency and the Illinois Environmental Regulatory Group (IERG) regarding the use of solubility as a limitation on the Class I and Class II groundwater standards. Some of this dialogue is reflected in a line of questioning initiated by Mr. Davis in the first hearing in Chicago, and the Agency and IERG continued this dialogue in a July 8 meeting at the Agency. Several key issues were discussed at this meeting.

The Illinois EPA has been administering 35 Ill. Adm. Code 742 "Tiered Approach to Corrective Action Objectives" ("TACO") since 1998. TACO has proven to be a complex, but flexible approach to the remediation of contaminated sites in Illinois and has been a model for the development of similar approaches in several other States.

There are a number of principles that underlie the successes of TACO. Two of those principles are pertinent to the discussion of water solubility as a basis for groundwater quality standards in this proceeding: (1) the risk-based principles

embodied in Tiers 1,2, and 3 of Part 742 and (2) the "speed bump" principles in Subpart C. The risk-based methodology allows the development of remediation objectives that are tailored to the specific contaminant risks pertinent to a site. The speed bump principles provide a methodology such that the contaminant source materials are removed from a site. As an example, groundwater cannot be excluded as a pathway of concern until free product is removed.

There is a close nexus between TACO and the Part 620 standards. The groundwater remediation objectives in TACO (Appendix B, Table E) were generally either taken from Part 620 or were developed using Part 620 methodologies to protect groundwater users. TACO has been updated as the Part 620 standards have changed over the years. Since the Part 620 standards are primarily health based in origin, TACO evaluations of the groundwater ingestion exposure route have likewise been health based in evaluating risk from the site contamination.

The current regulatory proceeding will result in changes to the Part 620 standards. In due course, TACO will be amended to reflect the Part 620 standards. Currently, Illinois EPA is working on a significant amendatory proposal to TACO that is intended to be filed with the Board later this summer. This proposal will incorporate a new pathway (indoor inhalation) and many changes to the Tier 1 remediation objectives based on more current toxicological information. We also intend the proposal to reflect the ongoing changes in this Part 620 proceeding.

As part of Illinois EPA's consultation with the Site Remediation Advisory Committee ("SRAC") with regards to our draft TACO proposal, it was brought to our attention that some of the proposed changes to the Part 620 standards, namely those based on solubility of contaminants, would have unintended, but potentially significant consequences for cleanups under TACO. The concern is that where groundwater quality standards are based on contaminant solubility rather than contaminant health risks the TACO groundwater <u>and soil</u> remediation objectives for those contaminants will no longer have a risk-based approach.

After reviewing the concerns raised by SRAC, we concur that the existing Agency proposal would have unintended consequences on TACO cleanups and should be modified. For example, for the contaminant anthracene, the existing Tier 1 soil remediation objective ("RO") for residential properties for the soil component of the groundwater ingestion exposure route is 12,000 mg/l, which would protect drinking water uses in Class I groundwater. If the groundwater quality standard is based on solubility (.043 mg/l) instead of risk to drinking water users (2.1 mg/l), then the calculated Tier 1 soil RO would drop two orders of magnitude from 12,000 mg/kg to 43 mg/kg. Illinois EPA believes that TACO should continue the risk-based approach it has followed to date.

Thus, as a result of the Agency dropping the solubility limitation, this request is now moot and no citations are provided. Note that where solubility had been listed in Mr. Cobb's testimony as the basis for a groundwater standard, the standard has been

replaced by the appropriate risk-based value in the attached Table 1 for Anthracene, Benzo(k)fluoranthene, Chrysene, Di-n-octyl phthalate, Fluoranthene, and Indeno(1,2,3-c,d)pyrene. Note also that for Benzo(a)pyrene and Methoxychlor, which already have existing standards, Mr. Cobb's testimony on page 17 states that the Class II standards should be changed to reflect water solubility; since solubility is no longer a basis for standards, these chemicals' existing Class II standards should not be changed, and these two chemicals should be removed from the proposal.

Question 9 - All of the proposed Class II standards, which are based on water solubility, are set at the same level as the Class I standards, except for benzo(a)pyrene, benzo(k)fluoranthene and methoxychlor. Please explain the Agency's intent.

Response to Question 9 – The question is now moot, as discussed above.

Question 10 - According to the table on page 16 of Mr. Cobb's pre-filed testimony and *errata* sheet No. 2, the proposed Class II standard for benzo(a)pyrene is 0.0016 mg/L. Further, on page 17 of Mr. Cobb's pre-filed testimony, he states that the existing Class II standard should be amended to 0.0002 mg/L based on its water solubility. Please clarify which value represents the limit based on water solubility of benzo(a)pyrene, 0.0016 mg/L or 0.0002 mg/L.

Response to Question 10 – The question is now moot, as discussed above.

Question 11 - The proposed Class II standards for explosive compounds at Section 620.420(c) are set at the same levels proposed for Class I groundwater. Please clarify whether the Koc values or the Henry's Law constants for these compounds are below threshold values considered by the Agency for setting standards based on treatability.

Response to Question 11 – The aforementioned thresholds are used when data is available on best available treatment ("BAT") technology research. Unfortunately no BAT studies were available for these contaminants. Thus, the proposed Class II standards were based on a 1X treatability factor.

Question 12 - On page 18 of Mr. Cobb's pre-filed testimony, regarding the proposed changes to the Class IV groundwater quality standards pertaining to explosive contaminants, he states that the designation of a previously mined area is being proposed because it moves the compliance point from the pit of the mine to the boundary of the permitted area in order to establish off-site contamination. Please clarify whether the proposed changes are intended to apply only to a "previously mined area" as defined in Section 620.110, which limits such area to land disturbed or affected by coal mining operations prior to February 1, 1983.

Response to Question 12 – Yes, the Illinois EPA intended for the proposed amendment to Subsection 620.440(d) to apply to a "previously mined area" as defined in Section 620.110, which limits such area to land disturbed or affected by coal mining operations prior to February1, 1983. This clarification is needed to reverse part of

what I provided in my testimony concerning the boundary of the permitted area. Since this mining was done pre-1983, there was no permit boundary.

Request 13 - On page 2 of Dr. Hornshaw's pre-filed testimony, he refers to a USEPA memorandum dated December 5, 2003, concerning Human Health Toxicity Values in Superfund Risk Assessments. Would the Agency be able to submit a copy of the memorandum?

Response to Request 13 – See the attached.

Question 14 - On page 3 of Dr. Hornshaw's pre-filed testimony, he notes that one of the issues concerning the new hierarchy of toxicity values pertains to the retirement of PPRTV by USEPA.

a. Please clarify whether retirement of a PPRTV for a chemical means that USEPA has established a permanent RfD for the chemical or just dropped the value from its database.

b. Also, does USEPA provide any explanation for retiring a PPRTV?

Response to Question 14(a)– It is the Toxicity Assessment Unit's understanding that entries into the PPRTV database have a 6-month time limit, after which the entry is retired and removed from the database. Since these retirements are not based on the quality of the data, we have decided to continue using the toxicity information. We are not aware of EPA's timetable for developing permanent RfDs and Sfos in IRIS or for "un-retiring" values and adding them back into the PPRTV database.

Response to Question 14(b)- We have not been provided with any explanations for retiring chemicals from the PPRTV database other than that there is a 6-month time limit.

Question 15 - On page 4 of Dr. Hornshaw's pre-filed testimony, regarding subchronic exposures, he states that the Agency used the IRIS values with the Uncertainty Factor removed for some of the chemical constituents as the first tier when available. Please identify the chemical constituents for which this procedure was used to develop the proposed standards.

Response to Question 15 – None. This was included in testimony only as an example of the issues that the Toxicity Assessment Unit had to resolve regarding the EPA hierarchy of toxicity information sources. Subchronic toxicity values are only used in conjunction with the construction worker soil ingestion exposure route in TACO, so no subchronic values were used to develop the proposed standards.

Question 16 - Also on page 4 of Dr. Hornshaw's pre-filed testimony, he states that changes needed in TACO because of the new hierarchy will be addressed when the next revision to the TACO rules are proposed to the Board. Please clarify whether the TACO groundwater objective for 1,1-Dichloroethane of 0.7 mg/L, which is lower than the proposed Class I standard of 1.4 mg/L, is one of the needed revisions.

Response to Question 16 – Yes.

Question 17 - On page 5 of Dr. Hornshaw's pre-filed testimony, he states that the Toxicity Assessment Unit decided to include in the proposal any chemical from the Bureau of Land's master list that had a toxicity value in the IRIS database. Please explain the rationale for limiting the chemicals to only those with IRIS toxicity values instead of considering the USEPA's three-tier hierarchy.

Response to Question 17 – As stated in Dr. Hornshaw's oral testimony in response to a similar question, the Toxicity Assessment Unit decided to include in the proposal any of the "new" chemicals (those not already in TACO) for which toxicity data were available in the IRIS and PPRTV databases. It was reasoned that these two sources provide nationally-accepted and peer-reviewed criteria as the basis for developing the new standards.

Question 18 - On page 7 of Dr. Hornshaw's pre-filed testimony, he states that additional corrections are necessary for several reasons, including the revision of the selection criteria for groundwater standards for carcinogenic chemicals. Dr. Hornshaw notes that the revised criteria require a comparison of each carcinogenic constituent's health based concentration (1 in million risk level) with its corresponding analytical MDL, the greater of which is compared with the constituent's reported water solubility.

a. Please clarify whether the analytical detection limit represents the carcinogenic constituent's MDL or its lowest Practical Quantitation Limit (PQL).

b. If the detection limit represents the MDL, should Part 620, Subpart F continue to refer to PQLs or should it be amended to state MDLs?

Response to Question 18(a)– As discussed above, all references to MDLs should be changed to PQLs.

Response to Question 18(b)- Continue to refer to PQLs.

II. CONCLUSION

This concludes the supplemental testimony of the Illinois EPA witnesses. We will be available to answer any questions.

Water Quality Criteria 1972

A Report of the
Committee on Water Quality Criteria

Environmental Studies Board

National Academy of Sciences
National Academy of Engineering

Washington, D.C., 1972

At the request of
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[illegible]

GENERAL TABLE OF CONTENTS

WATER FOR LIVESTOCK ENTERPRISES

Domestic animals represent an important segment of agriculture and are a vital source of food. Like man and many other life forms, they are affected by pollutants in their environment. This section is concerned primarily with considerations of livestock water quality and factors affecting it. These include the presence of ions causing excessive salinity, elements and ions which are toxic, biologically produced toxins, radionuclides, pesticide residues, and pathogenic and parasitic organisms.

Of importance in determining recommendations for these substances in livestock water supplies are the quantity of water an animal consumes per day and the concentration of the mineral elements in the water supply from which he consumes it. Water is universally needed and consumed by farm animals, but it does not account for their entire daily intake of a particular substance. Consequently, tolerance levels established for many substances in livestock feed do not accurately take into consideration the tolerance levels for those substances in water. Concentrations of nutrients and toxic substances in water affect an animal on the basis of the total amount consumed. Because of this, some assessment of the amounts of water consumed by live-stock on a daily basis and a knowledge of the probable quantity of elements in water and how they satisfy daily nutritional requirements are needed for determining possible toxicity levels.

WATER REQUIREMENTS FOR LIVESTOCK

The water content of animal bodies is relatively constant: 68 per cent to 72 per cent of the total weight on a fat-free basis. The level of water in the body usually cannot change appreciably without dire consequences to the animal; therefore, the minimal requirement for water is a reflection of water excreted from the body plus a component for growth in young animals (Robinson and McCance 1952,[53] Mitchell 1962[46]).

Water is excreted from the body in urine and feces, in evaporation from the lungs and skin, in sweat, and in productive secretions such as milk and eggs. Anything that influences any of these modes of water loss affects the minimal water requirement of the animal.

The urine contains the soluble products of metaboli that must be eliminated. The amount of urine excret daily varies with the feed, work, external temperature, wa consumption, and other factors. The hormone vasopres (antidiuretic hormone) controls the amount of urine affecting the reabsorption of water from the kidney tubu and ducts. Under conditions of water scarcity, an anim may concentrate its urine to some extent by reabsorbing greater amount of water than usual, thereby lowering t animal's requirement for water. This capacity for conce tration, however, is usually limited. If an animal consum excess salt or a high protein diet, the excretion of urine increased to eliminate the salt or the end products of pr tein metabolism, and the water requirement is thereb increased.

The amount of water lost in the feces varies dependin upon diet and species. Cattle, for instance, excrete fec with a high moisture content while sheep, horses, an chickens excrete relatively dry feces. Substances in the di that have a diuretic effect will increase water loss by thi route.

Water lost by evaporation from the skin and lungs (in sensible water loss) may account for a large part of th body's water loss approaching, and in some cases exceeding that lost in the urine. If the environmental temperature i increased, the water lost by this route is also increased Water lost through sweating may be considerable, especiall in the case of horses, depending on the environmental temperature and the activity of the animal.

All these factors and their interrelation make a minimal water requirement difficult to assess. There is also the additional complication that a minimal water requirement does not have to be supplied entirely by drinking water. The animal has available to it the water contained in feeds, the metabolic water formed from the oxidation of nutrients, water liberated by polymerization, dehydration, or synthesis within the body, and preformed water associated with nutrients undergoing oxidation when the energy balance is negative. All of these may vary. The water available from the feed will vary with the kind of feed and with the amount consumed. The metabolic water formed from the oxidation of nutrients may be calculated by the use of factors obtained from equations of oxidation of typical proteins, fats, and carbohydrates. There are 41, 107, and 60 grams (g) of water formed per 100 g of protein, fat, and carbohydrate oxidized, respectively. In fasting animals, or those subsisting on a protein deficient diet, water may be formed from the destruction of tissue protein. In general, it is assumed that tissue protein is associated with three times its weight of water, so that per gram of tissue protein metabolized, three grams of water are released.

It has been found by careful water balance trials that the water requirement of various species is a function of body surface area rather than weight. This implies that the requirements are a function of energy metabolism, and Adolph (1933)[43] found that a convenient liberal standard of total water intake is 1 milliliter (ml) per calorie (cal) of heat produced. This method automatically included the increased requirement associated with activity. Cattle require somewhat higher amounts of water (1.29 to 2.05 g/cal) than other animals. However, when cattle's large excretion of water in the feces is taken into account, the values are approximately a gram per calorie.

For practical purposes, water requirements can be measured as the amount of water consumed voluntarily under specified conditions. This implies that thirst is a result of need.

Water Consumption of Animals

In dry roughage and concentrate feeding programs the water present in the feed is so small relative to the animal's needs that it may be ignored (Winchester and Morris 1956).[55]

Beef Cattle. Data calculated by Winchester and Morris (1956)[55] indicated that values for water intake vary widely depending primarily on ambient temperature and dry matter intake. European breeds consumed approximately 3.5, 5.3, 7.0, and 17 liters of water daily per kilogram (kg) dry matter ingested at 40, 70, 90, 100 F, respectively. Thus at an atmospheric temperature of 21 C (70 F), a 450 kg steer on a 9.4 kg daily dry matter ration would consume approximately 50 liters of water per day, while at 32 C (90 F) the expected daily water intake would be 66 liters.

Dairy Cattle. The calculations of Winchester and Morris (1956)[55] showed how water requirements varied with weight of cow, fat content of milk, ambient temperature, and amount needed per kilogram of milk daily. These investigations indicated that at 21 C (70 F) a cow weighing approximately 450 kg would consume about 4.5 liters of water per kilogram dry feed plus 2.7 l/kg of milk produced. Dairy heifers fed alfalfa and silage obtained about 20 per cent of their water requirements in the feed. Dairy cattle suffer more quickly from a lack of water than from a shortage of any other nutrient and will drink 3.0 to 4.0 kg of water per kilogram of dry matter consumed (National Research Council, Committee on Animal Nutrition, hereafter referred to as NRC 1971a).[52] Cows producing 40 kg of milk per day may drink up to 110 kg of water when fed dry feeds.

Sheep. Generally water consumption by sheep amounts to two times the weight of dry matter feed intake (NRC 1968b).[51] But many factors may alter this value, e.g., ambient temperature, activity, age, stage of production, plane of nutrition, composition of feed, and type of pasture. Ewes on dry feed in winter require four liters per head daily before lambing and six or more liters per day when nursing lambs (Morrison 1959).[48]

Swine. Pigs require 2 to 2.5 kg of water per kilogram of dry feed, but voluntary consumption may be as much as 4 to 4.5 kg in high ambient temperature (NRC 1968a).[50] Mount et al. (1971)[49] reported the mean water:feed ratios were between 2.1 and 2.7 at temperatures between 7 and 22 C, and between 2.8 and 5.0 at 30 and 33 C. The range of mean water consumption extended from 0.092 to 0.184 l/kg body weight per day. Leitch and Thomson (1944)[45] cited studies that demonstrated that a water-to-mash ratio of 3:1 gave the best results.

Horses. Leitch and Thomson (1944)[45] cited data that horses needed two to three liters of water per kg dry ration. Morrison (1936)[47] obtained data of a horse going at a trot that gave off 9.4 kg of water vapor. This amount was nearly twice that given off when walking with the same load, and more than three times as much as when resting during the same period.

Poultry. James and Wheeler (1949)[44] observed that more water was consumed by poultry when protein was increased in the diet; and more water was consumed with meat scrap, fish meal, and dried whey diets than with an all-plant diet. Poultry generally consumed 2 to 3 kg of water per kilogram of dry feed. Sunde (1967)[54] observed that when laying hens, at 67 percent production, were deprived of water for approximately 36 hours, production dropped to eight per cent within five days and did not return to the production of the controlled hens until 25–30 days later. Sunde (*personal communication* 1971)[56] prepared a table that showed that broilers increased on daily water consumption from 6.4 to 211 liters per 1,000 birds between two and 35 days of age, respectively. Corresponding water intake values for replacement pullets were 5.7 to 88.5 liters.

RELATION OF NUTRIENT ELEMENTS IN WATER TO TOTAL DIET

All the mineral elements essential as dietary nutrients occur to some extent in water (Shirley 1970).[66] Generally the elements are in solution, but some may be present in suspended materials. Lawrence (1968)[59] sampled the Chattahoochee River system at six different reservoirs and river and creek inlets and found about 1, 3, 22, 39, 61, and 68 per cent of the total calcium, magnesium, zinc, manganese, copper, and iron present in suspended materials, respectively. Any given water supply requires analysis if dietary decisions are to be most effective.

In the Systems for Technical Data (STORET) of the Water Programs Office of the Environmental Protection Agency, data (1971)[69] were accumulated from surface water analyses obtained in the United States during the period 1957–1969. These data included values for the mean, maximum, and minimum concentrations of the nutrient elements (see Table V-1). These values obviously include many samples from calcium-magnesium, sulfate-chloride and sodium-potassium, sulfate-chloride type of water as well as the more common calcium-magnesium, carbonate-bicarbonate type. For this reason the mean values for sodium, chloride, and sulfate may appear somewhat high.

Table V-2 gives the estimated average intake of drinking water of selected categories of various species of farm animals expressed as liters per day. Three values for each of calcium and salt are given for illustrative purposes. One column expresses the National Academy of Sciences value for daily requirement of the nutrient per day; the second gives the amount of the element contributed by the average concentration of the element (calculated from data in Table V-1) in the average quantity of water consumed daily; the third column gives the approximate percentage of the daily requirements contributed by the water drunk each day for each species of animal.

Magnesium, calculated as in Table V-2, was found to be present in quantities that would provide 4 to 11 per cent of the requirements for beef and dairy cattle, sheep, swine, horses, chickens, and turkeys.

Cobalt (Co) concentrations obtained by Durum et al. (1971)[58] were calculated, as they were more typical of water available to livestock than current values reported in STORET (1971).[69] A sufficient amount of Co was present at the median level to supply approximately three to 13 per cent of the dietary requirements of beef and dairy cat sheep, and horses. The NRC (1971a,[65] 1968b[61]) does state what the cobalt requirements were for poultry a swine.

Sulfur values demonstrated that approximately 29 cent of beef cattle requirements were met at average co centrations; dairy cattle 21 to 45 per cent; sheep 10 to per cent; and horses 18 to 23 per cent of their requiremen The NRC (1971a,[65] 1968b[61]) do not give sulfur requireme for poultry and swine.

Iodine was not among the elements in the STOR accumulation, but values obtained by Dantzman a Breland (1970)[57] for 15 rivers and lakes in Florida can used as illustrative values. Iodine was present in sufficie amounts to exceed the requirements of beef cattle a nonlactating horses and to meet 8 to 10 per cent of t requirements of sheep and 24 to 26 per cent of those of her Phosphorus, potassium, copper, iron, zinc, manganese, ar selenium, when present at mean concentrations (Table V-1 would supply daily only one to four per cent or less of th recommended by the NRC (1966,[60] 1968a,[61] 1968b,[62] 1970, 1971a,[64] 1971b[65]) for beef and dairy cattle, sheep, swin horses, and poultry at normal water consumption levels.

If the maximum values shown in Table V-1 are presen some water would contain the dietary requirements of som species in the case of sodium chloride, sulfur, and iodin Appreciable amounts of calcium, copper, cobalt, iror

TABLE V-2—Daily Requirements of Average Concentra of Calcium and Salt in Water for Various Animals

Animal	Daily[a] water intake, l	Calcium			Salt[d]		
		Required[b] daily gm	Average[c] amt. in drinking water, gm	Approx percentage of Req. in water	Required[b] daily gm	Amt. in[c] drinking water, gm	P o.
Beef cattle 450 kg body wt.							
Nursing cow	60	28	3.4	12	25	8.5	
Finishing steer	60	21	3.4	16	24	8.5	
Dairy cattle 450 kg body wt.							
Lactating cow	90	76	5.1	7	66	12.7	
Growing heifer	60	15	3.4	22	21	8.5	
Maintenance, cow	60	12	3.4	28	21	8.5	
Sheep							
Lactating ewe, 64 kg	6	6.8	0.3	5	13	0.9	
Fattening lamb, 45 kg	4	3.1	0.2	7	10	0.6	
Swine							
Growing, 30 kg	6	10.2	0.34	3	4.3	0.84	
Fattening, 60 to 100 kg	8	16.5	0.46	3	4.3	1.12	
Lactating sows, 200–250 kg	14	33.0	0.80	2	28.0	1.96	
Horses 450 kg body wt							
Medium work	40	14	2.3	16	90	5.6	
Lactating	50	30	2.9	10	90	7.1	
Poultry							
Chickens, 8 weeks old	0.2	1.0	0.011	1	0.38	0.03	
Laying hen	0.2	3.4	0.011	<1	0.44	0.03	
Turkey	0.2	1.2	0.011	1	0.38	0.03	

[a] See discussion on Water Consumption in text for sources of these values.

[b] Sources of values are the National Academy of Sciences. NRC Bulletins on Nutrient requirements.

[c] Calculated from Table 1.

[d] Based on sodium in water.

TABLE V-1—Water Composition, United States, 1957–69 (STORET) (Collected at 140 stations)

Substance	Mean	Maximum	Minimum	No Detns.
Phosphorus, mg/l	0.087	5.0	0.001	1,729
Calcium, mg/l	57.1	173.0	11.0	510
Magnesium, mg/l	14.3	137.0	8.5	1,143
Sodium, mg/l	55.1	7,500.0	0.2	1,801
Potassium, mg/l	4.3	370.0	0.06	1,804
Chloride, mg/l	478.0	19,000.0	0.000	37,355
Sulfate, mg/l	135.9	3,383.0	0.000	30,229
Copper, μg/l	13.8	280.0	0.8	1,871
Iron, μg/l	43.9	4,600.0	0.10	1,836
Manganese, μg/l	29.4	3,230.0	0.20	1,818
Zinc, μg/l	51.8	1,183.0	1.0	1,883
Selenium, μg/l	0.016	1.0	0.01	234
Iodine[a], μg/l	46.1	336.0	4.0	15
Cobalt[b], μg/l	1.0	5.0	0.000	720

[a] Dantzman and Breland (1970)[57].

[b] Durum et al. (1971)[58].

manganese, zinc, and selenium would be present, if water were supplied with the maximum levels present. On the other hand, if the water has only the minimum concentration of any of the elements present, it would supply very little of the daily requirements.

It is generally believed that elements in water solution are available to the animal that consumes the water, at least as much as when present in solid feeds or dry salt mixes. This was indicated when Shirley et al. (1951,[67] 1957[68]) found that P^{32} and Ca^{45}, dissolved in aqueous solution as salts and administered as a drench, were absorbed at equivalent levels to the isotopes, when they were incorporated in forage as fertilizer and fed to steers, respectively. Many isotope studies have demonstrated that minerals in water consumed by animals are readily absorbed, deposited in their tissues, and excreted.

EFFECT OF SALINITY ON LIVESTOCK

It is well known that excessively saline waters can cause physiological upset or death of livestock. The ions most commonly involved in causing excessive salinity are calcium, magnesium, sodium, sulfate, bicarbonate, and chloride. Others may contribute significantly in unusual situations, and these may also exert specific toxicities separate from the osmotic effects of excessive salinity. (See Toxic Elements and Ions below.)

Early in this century, Larsen and Bailey (1913)[80] reported that a natural water varying from 4,546 to 7,369 mg/l of total salts, with sodium and sulfate ions predominating, caused mild diarrhea but no symptoms of toxicity in dairy cattle over a two-year period. Later, Ramsay (1924)[91] reported from his observations that cattle could thrive on water containing 11,400 mg/l of total salts, that they could live under certain conditions on water containing 17,120 mg/l, and that horses thrived on water with 5,720 mg/l and were sustained when not worked too hard on water with 9,140 mg/l.

The first extensive studies of saline water effects on rats and on livestock were made in Oklahoma (Heller and Larwood 1930,[76] Heller 1932,[74] 1933).[75] Rats were fed waters of various sodium chloride concentrations, and it was found among other things that (a) water consumption increased with salt concentration but only to a point after which the animals finally refused to drink until thirst drove them to it, at which time they drank a large amount at one time and then died; (b) older animals were more resistant to the effects of the salt than were the young; (c) the effects of salinity were osmotic rather than related to any specific ion; (d) reproduction and lactation were affected before growth effects were noted; (e) there appeared, in time, to be a physiological adjustment to saline waters; and (f) 15,000–17,000 mg/l of total salts seemed the maximum that could be tolerated, some adverse effects being noted at concentrations lower than this. With laying hens, 10,000 mg/l of sodium chloride in the drinking water greatly delayed the onset of egg production, but 15,000 mg/l or more were required to affect growth over a 10-week period. In swine, 15,000 mg/l of sodium chloride in the drinking water caused death in the smaller animals, some leg stiffness in the larger, but 10,000 mg/l did not appear particularly injurious once they became accustomed to it. Sheep existed on water containing 25,000 mg/l of sodium or calcium chloride or 30,000 mg/l of magnesium sulfate but not without some deleterious effects. Cattle were somewhat less resistant, and it was concluded that 10,000 mg/l of total salts should be considered the upper limit under which their maintenance could be expected. A lower limit was suggested for lactating animals. It was further observed that the animals would not drink highly saline solutions if water of low salt content was available, and that animals showing effects of saline waters returned quickly to normal when allowed a water of low salt content.

Frens (1946)[72] reported that 10,000 mg/l of sodium chloride in the drinking water of dairy cattle produced no symptoms of toxicity, while 15,000 mg/l caused a loss of appetite, decreased milk production, and increased water consumption with symptoms of salt poisoning in 12 days.

In studies with beef heifers, Embry et al. (1959)[71] reported that the addition of 10,000 mg/l of sodium sulfate to the drinking water caused severe reduction in its consumption, loss of weight, and symptoms of dehydration. Either 4,000 or 7,000 mg/l of added sodium sulfate increased water intake but had no effect on rate of gain or general health. Similar observations were made using waters with added sodium chloride or a mixture of salts, except that symptoms of dehydration were noted, and the mixed salts caused no increase in water consumption. Levels of up to 6,300 mg/l of added mixed salts increased water consumption in weanling pigs, but no harmful effects were observed over a three-month period.

In Australia, Peirce (1957,[83] 1959,[84] 1960,[85] 1962,[86] 1963,[87] 1966,[88] 1968a,[89] 1968b[90]) conducted a number of experiments on the salt tolerance of Merino wethers. Only minor harmful effects were observed in these sheep when they were confined to waters containing 13,000 mg/l or less of various salt mixtures.

Nevada workers have reported several studies on the effects of saline waters on beef heifers. They found that 20,000 mg/l of sodium chloride caused severe anorexia, weight loss, anhydremia, collapse, and certain other symptoms, while 10,000 mg/l had no effects over a 30-day period other than to increase water consumption and decrease blood urea (Weeth et al. 1960).[97] Additional experiments (Weeth and Haverland 1961)[98] again showed 10,000 mg/l to cause no symptoms of toxicity; while at 12,000 mg/l adverse effects were noted, and these intensified with increasing salt concentration in the drinking water. At a concentration of 15,000 mg/l, sodium chloride increased the ratio of urine excretion to water intake (Weeth and

Lesperance 1965),[100] and a prompt and distinct diuresis occurred when the heifers consumed water containing 5,000 or 6,000 mg/l following water deprivation (Weeth et al. 1968).[101] While with waters containing about 5,000 mg/l (Weeth and Hunter 1971)[99] or even less (Weeth and Capps 1971)[95] of sodium sulfate no specific ion effects were noted, heifers drank less, lost weight, and had increased methemoglobin and sulfhemoglobin levels. A later study (Weeth and Capps 1972)[96] gave similar results, but in addition suggested that the sulfate ion itself, at concentrations as low as 2150 mg/l had adverse effects.

In addition to the Oklahoma work, several studies on the effects of saline water on poultry have been reported. Selye (1943)[93] found that chicks 19 days old when placed on experiment had diarrhea, edema, weakness, and respiratory problems during the first 10 days on water containing 9,000 mg/l of sodium chloride. Later, the edema disappeared, but nephrosclerotic changes were noted. Water containing 3,000 mg/l of sodium chloride was not toxic to four-week-old chicks.

Others (Kare and Biely 1948)[77] observed that with two-day-old chicks on water containing 9,000 mg/l of added sodium chloride there were a few deaths, some edema, and certain other symptoms of toxicity. A solution with 18,000 mg/l of the salt was not toxic; however, when replaced on alternate days by fresh water, neither was it readily consumed.

Scrivner (1946)[92] found that sodium chloride in the drinking water of day-old poults at a concentration of 5,000 mg/l caused death and varying degrees of edema and ascites in over half of the birds in about two weeks. Sodium bicarbonate at a concentration of 1,000 mg/l was not toxic, at 3,000 mg/l caused some deaths and edema; and as the concentration increased above this, the effects were more pronounced. A solution containing 1,000 mg/l of sodium hydroxide caused death in two of 31 poults by 13 days, but the remainder survived without effects, and 7,500 mg/l of sodium citrate, iodide, carbonate, or sulfate each caused edema and many deaths.

South Dakota workers (Krista et al. 1961)[78] studied the effects of sodium chloride in water on laying hens, turkey poults, and ducklings. At 4,000 mg/l, the salt caused some increased water consumption, watery droppings, decreased feed consumption and growth, and increased mortality. These effects were more pronounced at a higher concentration, 10,000 mg/l, causing death in all of the turkey poults at two weeks, some symptons of dehydration in the chicks, and decreased egg production in the hens. Experiments with laying hens restricted to water containing 10,000 mg/l of sodium or magnesium sulfate gave results similar to those for sodium chloride.

TABLE V-3—Guide to the Use of Saline Waters for Livestock and Poultry

Total soluble salts content of waters (mg/l)	Comment
Less than 1,000	Relatively low level of salinity. Excellent for all classes of livestock and poultry.
1,000–2,999	Very satisfactory for all classes of livestock and poultry. May cause temporary and diarrhea in livestock not accustomed to them or watery droppings in poultry.
3,000–4,999	Satisfactory for livestock, but may cause temporary diarrhea or be refused at first by mals not accustomed to them. Poor waters for poultry, often causing water feces, incre mortality, and decreased growth, especially in turkeys.
5,000–6,999	Can be used with reasonable safety for dairy and beef cattle, for sheep, swine, and hc Avoid use for pregnant or lactating animals. Not acceptable for poultry.
7,000–10,000	Unfit for poultry and probably for swine. Considerable risk in using for pregnant or lact. cows, horses, or sheep, or for the young of these species. In general, use should be avc although older ruminants, horses, poultry, and swine may subsist on them under ce conditions.
Over 10,000	Risks with these highly saline waters are so great that they cannot be recommended for under any conditions.

In addition to the experimental work, there have been reports in the literature of field observations relating to the effects of excessively saline water (Ballantyne 1957,[70] Gastler and Olson 1957,[73] Spafford 1941[94]), and a number of guides to the use of these waters for livestock have bee published (Ballantyne 1957,[70] Embry et al. 1959,[71] Kris et al. 1962,[79] McKee and Wolf, 1963,[81] Officers of tl Department of Agriculture and the Government Chemic Laboratories 1950,[82] Spafford, 1941[94]). Table V-3 is basc on the available published information. Among other thing the following items are suggested for consideration in usin this table:

- Animals drink little, if any, highly saline water water of low salt content is available to them.
- Unless they have been previously deprived of wate animals can consume moderate amounts of highl saline water for a few days without being harmed.
- Abrupt changes from water of low salinity to highl saline water cause more problems than a gradua change.
- Depressed water intake is very likely to be accom panied by depressed feed intake.

Table V-3 was developed because in arid or semiaric regions the use of highly saline waters may often be necessary. It has built into it a very small margin of safety, and its use probably does not eliminate all risk of economic loss.

Criteria for desirability of a livestock water are a somewhat different matter. These should probably be such that the risk of economic loss from using the water for any species or age of animals, lactating or not, on any normal feeding program, and regardless of climatic conditions, is almost nonexistent. On the other hand, they should be made no more severe than necessary to insure this small risk.

Recommendation

From the standpoint of salinity and its osmotic effects, waters containing 3,000 mg of soluble salts per liter or less should be satisfactory for livestock under almost any circumstance. While some minor physiological upset resulting from waters with

salinities near this limit may be observed, economic losses or serious physiological disturbances should rarely, if ever, result from their use.

TOXIC SUBSTANCES IN LIVESTOCK WATERS

There are many substances dissolved or suspended in waters that may be toxic. These include inorganic elements and their salts, certain organic wastes from man's activities, pathogens and parasitic organisms, herbicide and pesticide residues, some biologically produced toxins, and radionuclides.

For any of the above, the concentrations at which they render a water undesirable for use for livestock is subject to a number of variables. These include age, sex, species, and physiological state of the animals: water intake, diet and its composition, the chemical form of any toxic element present, and the temperature of the environment. Naturally, if feeds and waters both contain a toxic substance, this must be taken into account. Both short and long term effects and interactions with other ions or compounds must also be considered.

The development of recommendations for safe concentrations of toxic substances in water for livestock is extremely difficult. Careful attention must be given to the discussion that follows as well as the recommendations and to any additional experimental findings that may develop. Based on available research, an appropriate margin of safety, under almost all conditions, of specific toxic substances harmful to livestock that drink the waters and to man who consumes the livestock or their products, is reviewed below. Although the margin of safety recommended is usually large, the criteria suggested cannot be used as a guide in diagnosing livestock losses, since they are well below toxic levels for domestic animals.

Toxic Elements and Ions

Those ions largely responsible for salinity in water (sodium, calcium, magnesium, chloride, sulfate, and bicarbonate) are in themselves not very toxic. There are, however, a number of others that occur naturally or as the result of man's activities at troublesome concentrations. If feeds and water both contain a toxic ion, both must be considered. Interactions with other ions, if known, must be taken into account. Elements or ions become objectionable in water when they are at levels toxic to animals, where they seriously reduce the palatability of the water, or when they accumulate excessively in tissues or body fluids, rendering the meat, milk, eggs, or other edible product unsafe or unfit for human use.

Aluminum

Soluble aluminum has been found in surface waters of the United States in amounts to 3 mg/l, but its occurrence at such concentrations is rare because it readily precipitates as the hydroxide (Kopp and Kroner 1970).[182] Most edible grasses contain about 15–20 mg/kg of the element. However, there is no evidence that it is essential for animal growth, and very little is found deposited in animal tissues (Underwood 1971).[254] It is not highly toxic (McKee and Wolf 1963,[193] Underwood 1971),[254] but Deobald and Elvehjem (1935)[135] found that a level of 4,000 mg aluminum per kilogram of diet caused phosphorus deficiency in chicks. Its occurrence in water should not cause problems for livestock, except under unusual conditions and with acid waters.

Recommendation.

Livestock should be protected where natural drinking waters contain no more than 5 mg/l aluminum.

Arsenic

Arsenic has long been notorious as a poison. Nevertheless, it is present in all living tissues in the inorganic and in certain organic forms. It has also been used medicinally. It is accepted as a safe feed additive for certain domestic animals. It has not been shown to be a required nutrient for animals, possibly because its ubiquity has precluded the compounding of deficient diets (Frost 1967).[149]

The toxicity of arsenic can depend on its chemical form, its inorganic oxides being considerably more toxic than organic forms occurring in living tissues or used as feed additives. Differences in toxicities of the various forms are clearly related to the rate of their excretion, the least toxic being the most rapidly eliminated (Frost 1967,[149] Underwood 1971).[254] Except in unusual cases, this element should occur in waters largely as inorganic oxides. In waters carrying or in contact with natural colloidal material, the soluble arsenic content may be decreased to a very low level by adsorption.

Wadsworth (1952)[260] gave the acute toxicity of inorganic arsenic for farm animals as follows: poultry, 0.05–0.10 g per animal; swine, 0.5–1.0 g per animal; sheep, goats, and horses, 10.0–15.0 g per animal; and cattle, 15–30 g per animal. Franke and Moxon (1936)[148] concluded that the minimum dose required to kill 75 per cent of rats given intraperitoneal injections of arsenate was 14–18 mg arsenic per kilogram, while for arsenite it was 4.25–4.75 mg/kg of body weight.

When mice were given drinking water containing 5 mg/l of arsenic as arsenite from weaning to natural death, there was some accumulation of the element in the tissues of several organs, a somewhat shortened life span, but no carcinogenic effect (Schroeder and Balassa 1967).[233] In a similar study with rats (Schroeder et al. 1968b),[236] neither toxicity nor carcinogenic effects were observed, but large amounts accumulated in the tissues.

Peoples (1964)[220] fed arsenic acid at levels up to 1.25 mg/kg of body weight per day for eight weeks to lactating cows. This is equivalent to an intake of 60 liters of water containing 5.5 mg/l of arsenic (10.4 mg of arsenic acid) daily by a 500 kg animal. His results indicated that this form of arsenic is absorbed and rapidly excreted in the urine. Thus there was little tissue storage of the element: at no level of the added arsenic was there an increased arsenic content of the milk, and no toxicity was observed.

According to Frost (1967),[149] there is no evidence that 10 parts per million (ppm) of arsenic in the diet is toxic to any animal.

Arsenicals have been accused of being carcinogenic. This matter has been thoroughly reviewed by Frost (1967),[149] who concluded that they appear remarkably free of this property.

Most human foods contain less than 0.5 ppm of arsenic, but certain marine animals used as human food may concentrate it and may contain over 100 ppm (Frost 1967,[149] Underwood 1971[254]). Permissible levels of the element in muscle meats is 0.5 ppm; in edible meat by-products, 1.0 ppm; and in eggs, 0.5 ppm (U.S. Dept. of Health, Education, and Welfare, Food and Drug Administration 1963,[255] 1964[256]). Federal Drinking Water Standards list 0.05 mg/l as the upper allowable limit to humans for arsenic, but McKee and Wolf (1963)[193] suggested 1.0 mg/l as the upper limit for livestock drinking water. The possible role of biological methylation in increasing the toxicity (Chemical Engineering News 1971)[126] suggested added caution, however, and natural waters seldom contain more than 0.2 mg/l (Durum et al. 1971).[141]

Recommendation

To provide the necessary caution, and in view of available data, an upper limit of 0.2 mg/l of arsenic in water is recommended.

Beryllium

Beryllium was found to occur in natural surface waters only at very low levels, usually below 1 μg/l (Kopp and Kroner 1970).[182] Conceivably, however, it could enter waters in effluents from certain metallurgical plants. Its salts are not highly toxic, laboratory rats having survived for two years on a diet that supplied the element at a level of about 18 mg/kg of body weight daily. Pomelee (1953)[223] calculated that a cow could drink almost 1,000 liters of water containing 6,000 mg/l without harm, if these data for rats are transposable to cattle. This type of extrapolation must, however, be used with caution, and the paucity of additional data on the toxicity of beryllium to livestock precludes recommending at this time a limit for its concentration in livestock waters.

Boron

The toxicity of boron, its occurrence in foods and feeds, and its role in animal nutrition have been reviewed by McClure (1949),[190] McKee and Wolf (1963),[193] and Underwood (1971).[254] Although essential for plants, there is no evidence that boron is required by animals. It h relatively low order of toxicity. In the dairy cow, 16– of boric acid per day for 40 days produced no ill ef (McKee and Wolf 1963).[193]

There is no evidence that boron accumulates to great extent in body tissues. Apparently, most nat waters could be expected to contain concentrations below the level of 5.0 mg/l. This was the maximum amo found in 1,546 samples of river and lake waters f various parts of the United States, the mean value b 0.1 mg/l (Kopp and Kroner 1970).[182] Ground waters c contain substantially more than this at certain places.

Recommendation

Experimental evidence concerning the toxic of this element is meager. Therefore, to offer large margin of safety, an upper limit of 5.0 m of boron in livestock waters is recommended.

Cadmium

Cadmium (Cd) is normally found in natural waters very low levels. A nationwide reconnaissance of surf waters of the United States (Durum et al. 1971)[141] revea that of over 720 samples, about four per cent contained o 10 μg/l of this element, and the highest level was 110 μg Ground water on Long Island, New York, contained mg/l as the result of contamination by waste from the el troplating industry, and mine waters in Missouri contain 1,000 mg/l (McKee and Wolf 1963).[193]

Research to date suggests that cadmium is not an essen element. It is, on the other hand, quite toxic. Man has be sickened by about 15 ppm in popsicles, 67 ppm in punc 300 ppm in a cold drink, 530 ppm in gelatin, and 14.5 taken orally; although a family of four whose drinki water was reported to contain 47 ppm had no history of effects (McKee and Wolf 1963).[193]

Extensive tests have been made on the effects of vario levels of cadmium in the drinking water on rats and do (McKee and Wolf 1963).[193] Because of the accumlati and retention of the element in the liver and kidney, it w recommended that a limit of 100 μg/l, or preferably less, used for drinking waters.

Parizek (1960)[219] found that a single dose of 4.5 mg Cd k of body weight produced permanent sterility in male ra At a level of 5 mg/l in the drinking water of rats (Schroede et al. 1963a)[238] or mice (Schroeder et al. 1963b),[239] reduce longevity was observed. Intravenous injection of cadmiu sulfate into pregnant hamsters at a level of 2 mg Cd k of body weight on day eight of gestation caused malformations in the fetuses (Mulvihill et al. 1970).[200]

Miller (1971)[196] studied cadmium absorption and distribution in ruminants. He found that only a small part o ingested cadmium was absorbed, and that most of what wa went to the kidneys and liver. Once absorbed, its turnove rate was very slow. The cow is very efficient in keeping cadmium out of its milk, and Miller concluded that most major animal products, including meat and milk, seemed quite well protected against cadmium accumulation.

Interactions of cadmium with several other trace elements (Hill et al. 1963,[172] Gunn and Gould 1967,[159] Mason and Young 1967)[189] somewhat confuse the matter of establishing criteria.

Recommendation

From the available data on the occurrence of cadmium in natural waters, its toxicity, and its accumulation in body tissues, an upper limit of 50 μg/l allows an adequate margin of safety for livestock and is recommended.

Chromium

In a five-year survey of lake and river waters of the United States (Kopp and Kroner 1970),[182] the highest level found in over 1,500 samples was about 0.1 mg/l, the average being about 0.001 mg/l. In another similar survey (Durum et al. 1971)[141] of 700 samples, none contained over 0.05 mg/l of chromium VI and only 11 contained more than 0.005 mg/l. A number of industrial processes however use the element, which then may be discharged as waste into surface waters, possibly at rather high levels.

Even in its most soluble forms, the element is not readily absorbed by animals, being largely excreted in the feces; and it does not appear to concentrate in any particular mammalian tissue or to increase in these tissues with age (Mertz 1967,[194] Underwood 1971[254]).

Hexavalent chromium is generally considered more toxic than the trivalent form (Mertz 1967).[194] However, in their review of this element, McKee and Wolf (1963)[193] suggested that it has a rather low order of toxicity. Further, Gross and Heller (1946)[158] found that for rats the maximum nontoxic level, based on growth, for chromium VI in the drinking water was 500 mg/l. They also found that this concentration of the element in the water did not affect feed utilization by rabbits. Romoser et al. (1961)[226] found that 100 ppm of chromium VI in chick diets had no effect on the performance of the birds over a 21-day period.

In a series of experiments, Schroeder et al. (1963a,[238] 1963b,[239] 1964,[234] 1965[235]) administered water containing 5 mg/l of chromium III to rats and mice on low-chromium diets over a life span. At this level, the element was not toxic, but instead it had some beneficial effects. Tissue levels did not increase significantly with age.

As a result of their review of chromium toxicity, McKee and Wolf (1963)[193] suggested that up to 5 mg/l of chromium III or VI in livestock drinking water should not be harmful. While this may be reasonable, it may be unnecessarily high when the usual concentrations of the element in natural waters is considered.

Recommendation

An upper allowable limit of 1.0 mg/l for livestock drinking waters is recommended. This provides a suitable margin of safety.

Cobalt

In a recent survey of surface waters in the United States (Durum et al. 1971)[141] 63 per cent of over 720 samples were found to contain less than 0.001 mg/l of cobalt. One sample contained 4.5 mg/l, one contained 0.11 mg/l, and three contained 0.05–0.10 mg/l.

Underwood (1971)[254] reviewed the role of cobalt in animal nutrition. This element is part of the vitamin B_{12} molecule, and as such it is an essential nutrient. Ruminants synthesized their own vitamin B_{12} if they were given oral cobalt. For cattle and sheep a diet containing about 0.1 ppm of the element seemed nutritionally adequate. A wide margin of safety existed between the required and toxic levels for sheep and cattle, which were levels of 100 times those usually found in adequate diets being well tolerated.

Nonruminants required preformed vitamin B_{12}. When administered to these animals in amounts well beyond those present in foods and feeds, cobalt induced polycythemia (Underwood 1971).[254] This was also true in calves prior to rumen development: about 1.1 mg of the element per kg of body weight administered daily caused depression of appetite and loss of weight.

Cobalt toxicity was also summarized by McKee and Wolf (1963).[193]

Recommendation

In view of the data available on the occurrence and toxicity of cobalt, an upper limit for cobalt in livestock waters of 1.0 mg/l offers a satisfactory margin of safety, and should be met by most natural waters.

Copper

The examination of over 1,500 river and lake waters in the United States (Kopp and Kroner 1970)[182] yielded, at the highest, 0.28 mg/l of copper and an average value of 0.015 mg/l. These rather low values were probably due in part to the relative insolubility of the copper ion in alkaline medium and to its ready adsorbability on colloids (McKee and Wolf 1963).[193] Where higher values than those reported above are found, pollution from industrial sources or mines can be suspected.

Copper is an essential trace element. The requirement for chicks and turkey poults from zero to eight weeks of age is 4 ppm in the diet (NRC 1971b).[206] For beef cattle on rations low in molybdenum and sulfur, 4 ppm in the diet is adequate; but when these elements are high, the copper requirement is doubled or tripled (NRC 1970).[204] A dietary level of 5 ppm in the forage is suggested for pregnant and lactating ewes and their lambs (NRC 1968b[203]). A level of 6 ppm in the diet is considered adequate for swine (NRC 1968a).[202]

Swine are apparently very tolerant of high levels of copper, and 250 ppm or more in the diet have been used to improve liveweight gains and feed efficiency (Nutrition Reviews 1966a[210]; NRC 1968a).[202] On the other hand, sheep were very susceptible to copper poisoning (Underwood 1971),[254] and for these animals a diet containing 25 ppm was considered toxic. About 9 mg per animal per day was considered the safe tolerance level (NRC 1968b).[203]

Several reviews of copper requirements and toxicity have been presented (McKee and Wolf 1963,[193] Nutrition Reviews 1966a,[210] Underwood 1971).[254] There is very little experimental data on the effects of copper in the water supply on animals, and its toxicity must be judged largely from the results of trials where copper was fed. The element does not appear to accumulate at excessive levels in muscle tissues, and it is very readily eliminated once its administration is stopped. While most livestock tolerate rather high levels, sheep do not (NRC 1968b).[203]

Recommendation

It is recommended that the upper limit for copper in livestock waters be 0.5 mg/l. Very few natural waters should fail to meet this.

Fluorine

The role of fluorine as a nutrient and as a toxin has been thoroughly reviewed by Underwood (1971).[254] (Unless otherwise indicated, the following discussion, exclusive of the recommendation, is based upon this review.) While there is no doubt that dietary fluoride in appropriate amounts improved the caries resistance of teeth, the element has not yet been found essential to animals. If it is a dietary essential, its requirement must be very low. Its ubiquity probably insures a continuously adequate intake by animals.

Chronic fluoride poisoning of livestock has, on the other hand, been observed in several areas of the world, resulting in some cases from the consumption of waters of high fluoride content. These waters come from wells in rock from which the element has been leached, and they often contain 10–15 mg/l. Surface waters, on the other hand, usually contain considerably less than 1 mg/l.

Concentrations of 30–50 ppm of fluoride in the total ration of dairy cows is considered the upper safe limit, higher values being suggested for other animals (NRC 1971a).[205] Maximum levels of the element in waters that are tolerated by livestock are difficult to define from available experimental work. The species, volume, and continuity of water consumption, other dietary fluoride, and age of the animals, all have an effect. It appears, however, that as little as 2 mg/l may cause tooth mottling under some circumstances. At least a several-fold increase in its concentrat seems, however, required to produce other injurious effe

Fluoride from waters apparently does not accumulate soft tissues to a significant degree. It is transferred to a v small extent into the milk and to a somewhat greater deg into eggs.

McKee and Wolf (1963)[193] have also reviewed the mat of livestock poisoning by fluoride, concluding that 1.0 m of the element in their drinking water did not harm th animals. Other more recent reports presented data sugge ing that even considerably higher concentrations of fluori in the water may, with the exception of tooth mottlin caused no animal health problems (Harris et al. 1963, Shupe et al. 1964,[246] Nutrition Reviews 1966b,[211] Savi 1967,[231] Schroeder et al. 1968a[237]).

Recommendation

An upper limit for fluorides in livestock drinkin waters of 2.0 mg/l is recommended. Although thi level may result in some tooth mottling it shoul not be excessive from the standpoint of anima health or the deposition of the element in mea milk, or eggs.

Iron

It is well known that iron (Fe) is essential to animal life Further, it has a low order of toxicity. Deobald and Elvehjem (1935)[138] found that iron salts added at a level o 9,000 mg Fe/kg of diet caused a phosphorus deficiency in chicks. This could be overcome by adding phosphate to the diet. Campbell (1961)[124] found that soluble iron salt administered to baby pigs by stomach tube at a level of 600 mg Fe/kg of body weight caused death within six hours. O'Donovan et al. (1963)[212] found very high levels of iron in the diet (4,000 and 5,000 mg/kg) to cause phosphorus deficiency and to be toxic to weanling pigs. Lower levels (3,000 mg/kg) apparently were not toxic. The intake of water by livestock may be inhibited by high levels of this element (Taylor 1935).[250] However, this should not be a common or a serious problem. While iron occurs in natural waters as ferrous salts which are very soluble, on contact with air it is oxidized and it precipitates as ferric oxide, rendering it essentially harmless to animal health.

It is not considered necessary to set an upper limit of acceptability for iron in water. It should be noted, however, that even a few parts per million of iron can cause clogging of lines to stock watering equipment or an undesirable staining and deposit on the equipment itself.

Lead

Lake and river waters of the United States usually contain less than 0.05 mg/l of lead (Pb), although concentrations in excess of this have been reported (Durum et al. 1971,[141] Kopp and Kroner 1970).[182] Some natural waters in areas where galena is found have had as much as 0.8 mg/l of the element. It may also be introduced into waters in the effluents from various industries, as the result of action of the water on lead pipes (McKee and Wolf 1963),[193] or by deposition from polluted air (NRC 1972).[207]

A nutritional need for lead by animals has not been demonstrated, but its toxicity is well known. A rather complete review of the matter of lead poisoning by McKee and Wolf (1963)[193] suggested that for livestock the toxicity of the element had not been clearly established from a quantitative standpoint. Even with more recent data (Donawick 1966,[139] Link and Pensinger 1966,[186] Harbourne et al. 1968,[165] Damron et al. 1969,[131] Hatch and Funnell 1969,[168] Egan and O'Cuill 1970,[143] Aronson 1971),[108] it is difficult to establish clearly at what level of intake lead becomes toxic, although a daily intake of 6–7 mg Pb/kg of body weight has been suggested as the minimum that eventually gave rise to signs of poisoning in cattle (Hammond and Aronson 1964).[164] Apparently, cattle and sheep are considerably more resistant to lead toxicosis than are horses, being remarkably tolerant to the continuous intake of relatively large amounts of the element (Hammond and Aronson 1964,[164] Garner 1967,[152] Aronson 1971[108]; NRC 1972[207]). However, there is some tendency for it to accumulate in tissues and to be transferred to the milk at levels that could be toxic to man (Hammond and Aronson 1964).[164]

There is some agreement that 0.5 mg/l of lead in the drinking water of livestock is a safe level (McKee and Wolf 1963);[193] and the findings of Schroeder and his associates with laboratory animals are in agreement with this (1963a,[238] 1963b,[239] 1964,[234] 1965[235]). Using 10 times this level, or 5 mg/l, of lead in the drinking water of rats and mice over their life spans, these authors observed no obvious direct toxic effects but did find an increase in death rates in the older animals, especially in the males. Schroeder et al. (1965)[235], observed that the increased mortality was not caused by overt lead poisoning, but rather by an increased susceptibility to spontaneous infections. Hemphill et al. (1971)[171] later reported that mice treated with subclinical doses of lead nitrate were more susceptible to challenge with *Salmonella typhimurium*.

Recommendation

In view of the lack of information concerning the chronic toxicity of lead, its apparent role in reducing disease resistance, and the very low incidence in natural waters of lead contents exceeding the 0.05 mg/l level, an upper limit of 0.1 mg/l for lead in livestock waters is recommended.

Manganese

Like iron, manganese is a required trace element, occurs in natural waters at only low levels as manganous salts, and is precipitated in the presence of air as manganic oxide. While it can be toxic when administered in the feed at high levels (Underwood 1971),[254] it is improbable that it would be found at toxic levels in waters.

It is doubtful that setting an upper limit of acceptability is necessary for manganese, but as with iron, a few milligrams per liter in water can cause objectionable deposits on stock watering equipment.

Mercury

Natural waters may contain mercury originating from the activities of man or from naturally occurring geological stores (Wershaw 1970,[262] White et al. 1970).[263] The element tends to sorb readily on a variety of materials, including the bottom sediments of streams, greatly reducing the levels that might otherwise remain in solution (Hem 1970).[170] Thus, surface waters in the United States have usually been found to contain much less than 5 μg/l of mercury (Durum et al. 1971).[141] In areas harboring mercury deposits, their biological methylation occurs in bottom sediments (Jensen and Jernelöv 1969)[176] resulting in a continuous presence of the element in solution (Greeson 1970).[156]

In comparison to the relative instability of organic compounds such as salts of phenyl mercury and methoxyethyl mercury (Gage and Swan 1961,[151] Miller et al. 1961,[195] Daniel and Gage 1969,[132] Daniel et al. 1971[133]) alkyl mercury compounds including methyl mercury (CH_3Hg^+) have a high degree of stability in the body (Gage 1964,[150] Miller et al. 1961)[195] resulting in an accumulative effect. This relative stability, together with efficient absorption from the gut, contributes to the somewhat greater toxicity of orally administered methyl mercury as compared to poorly absorbed inorganic mercury salts (Swensson et al. 1959).[249]

The biological half-life of methyl mercury varies from about 20 to 70 days in most species (Bergrund and Berlin 1969).[113] Brain, liver, and kidney were the organs that accumulated the highest levels of the element, with the distribution of methyl and other alkyl mercury compounds favoring nerve tissue and inorganic mercury favoring the kidney (Malishevskaya et al. 1966,[188] Platonow 1968,[222] Aberg et al. 1969).[102]

Transfer of methyl mercury (Curley et al. 1971),[130] but not mercuric mercury (Berlin and Ullberg 1963),[114] to the fetus has been observed. The element also appeared in the eggs of poultry (Kiwimae et al. 1969)[180] and wild birds (Borg et al. 1969,[118] Dustman et al. 1970)[142] but did not seem to concentrate there much above levels found in the tissues of the adult. Data concerning levels of mercury that may be detrimental to hatchability of eggs are too meager to support conclusions at this time. Also, data concerning transfer of mercury to milk is lacking.

The animal organs representing the principal tissues for mercury concentration are brain, liver, and kidney. It is desirable that the maximum allowable limit for mercury in livestock waters should result in less than 0.5 ppm of accumulated mercury in these tissues. This is the level now in use as the maximum allowable in fish used for human consumption.

Few data are available quantitatively relating dietary mercury levels with accumulation in animal tissues. The ratios between blood and brain levels of methyl mercury appeared to range from 10 for rats to 0.2 for monkeys and dogs (International Committee on Maximum Allowable Concentrations of Mercury Compounds 1969).[174] In addition, blood levels of mercury appeared to increase approximately in proportion to increases in dietary intake (Birke et al. 1967[115]; Tejning 1967[251]).

Assuming a 0.2 or more blood-to-tissue (brain or other tissue) ratio for mercury in livestock, the maintenance of less than 0.5 ppm mercury in all tissues necessitates maintaining blood mercury levels below 0.1 ppm. This would indicate a maximum daily intake of 2.3 µg of mercury per kilogram body weight. Based upon daily water consumption by meat animals in the range of up to about eight per cent of body weight, it is estimated that water may contain almost 30 µg/l of mercury as methyl mercury without the limits of these criteria being exceeded. Support for this approximation was provided in part by the calculations of Aberg et al. (1969)[102] showing that after "infinite" time the body burden of mercury in man will approximate 15.2 times the weekly intake of methyl mercury. Applying these data to meat animals consuming water equivalent to eight per cent of body weight and containing 30 µg/l of mercury would result in an average of 0.25 ppm mercury in the whole animal body.

Recommendation

Until specific data become available for the various species, adherence to an upper limit of 10 µg/l of mercury in water for livestock is recommended, and this limit provides an adequate margin of safety to humans who will subsequently not be exposed to as much as 0.5 ppm of mercury through the consumption of animal tissue.

Molybdenum

Underwood (1971)[254] reviewed the matter of molybdenum's role in animal nutrition. While the evidence that it is an essential element is good, the amount of molybdenum required has not been established. For cattle, for instance, no minimum requirement has been set, but it is believed to be low, possibly less than 0.01 ppm of the dry diet (NRC 1970).[204]

McKee and Wolf (1963)[193] reviewed the matter of toxicity of molybdenum to animals, but Underwood (1971)[254] pointed out that many of the studies on its toxicity are of limited value because a number of factors known to influence its metabolism were not taken into account in making these studies. These factors included the chemical form of molybdenum, the copper status and intake of the animal, the form and amount of sulfur in the diet, and other less well defined matters. In spite of these, there are data to support real species differences in terms of tolerance to element. Cattle seem the least tolerant, sheep a little m so, and horses and swine considerably more tolerant.

While Shirley et al. (1950)[245] found that drenching ste daily with sodium molybdate in an amount equialent about 200 ppm of molybdenum in the diet for a period seven months resulted in no marked symptoms of toxici cattle on pastures where the herbage contained 20–100 p of molybdenum on a dry basis developed a toxicosis kno as teart. Copper additions to the diet have been used control this (Underwood 1971).[254]

Cox et al. (1960)[127] reported that rats fed diets containi 500 and 800 ppm of added molybdenum showed toxic symptoms and had increased levels of the element in th livers. Some effects of the molybdenum in the diets on li enzymes in the rats were not observed in calves that h been maintained on diets containing up to 400 ppm of element.

Apparently, natural surface waters very rarely contain levels of this element of over 1 mg/l (Kopp and Kror 1970),[182] which seemed to offer no problem.

Conclusion

Because there are many factors influencing to icity of molybdenum, setting an upper allowab limit for its concentration in livestock waters not possible at this time.

Nitrates and Nitrites

Livestock poisoning by nitrates or nitrites is depende upon the intake of these ions from all sources. Thus, wat or forage may independently or together contain levels th are toxic. Of the two, nitrite is considerably more toxi Usually it is formed through the biological reduction nitrate in the rumen of cattle or sheep, in freshly choppe forage, in moistened feeds, or in waters contaminated wi organic matter to the extent that they are capable of su porting microbial growth. While natural waters often co tain high levels of nitrate, their nitrite content is usual very low.

While some nitrate was transferred to the milk, Daviso and his associates (1964)[135] found that for dairy cattle fe 150 mg NO_3N/kg of body weight the milk contained abou 3 ppm of NO_3N. They concluded that nitrates in cattl feeds did not appear to constitute a hazard to huma health, and that animals fed nitrate continuously develope some degree of adaptation to it.

The LD50 of nitrate nitrogen for ruminants was foun to be about 75 mg NO_3N/kg of body weight when administered as a drench (Bradley et al. 1940)[119] and abou 255 mg/kg of body weight when sprayed on forage an feed (Crawford and Kennedy 1960).[128] Levels of 60 m NO_3N/kg of body weight as a drench (Sapiro et al. 1949)[23] and 150 mg NO_3N/kg of body weight in the diet (Prewit and Merilan 1958;[224] Davison et al. 1964[135]) had no deleterious effects. Lewis (1951)[184] found that 60 per cent conversion of hemoglobin to methemoglobin occurred in mature sheep from 4.0 g of NO_3N or 2.0 g of NO_2N placed in the rumen, or 0.4 g NO_2N injected intravenously. As an oral drench, 90 mg NO_3N/kg of body weight gave peak methemoglobin levels of 5–6 g/100 ml of blood in sheep, while intravenous injection of 6 mg NO_2N/kg of body weight gave similar results (Emerick et al. 1965).[144]

Nitrate-induced abortions in cattle and sheep have generally required amounts approaching lethal levels (Simon et al. 1959,[247] Davison et al. 1962,[136] Winter and Hokanson 1964,[266] Davison et al. 1965[137]).

Some experiments have demonstrated reductions in plasma or liver vitamin A values resulting from the feeding of nitrate to ruminants (Jordan et al. 1961,[175] Goodrich et al. 1964,[153] Newland and Deans 1964,[209] Hoar et al. 1968[173]). The destructive effect of nitrites on carotene (Olson et al. 1963[213]) and vitamin A (Pugh and Garner 1963[225]) under acid conditions that existed in silage or in the gastric stomach have also been noted. On the other hand, nitrate levels of about 0.15 per cent in the feed (equivalent to about 1 per cent of potassium nitrate) have not been shown to influence liver vitamin A levels (Hale et al. 1962,[161] Weichenthal et al. 1963,[261] Mitchell et al. 1967[197]) nor to have other deleterious effects in controlled experiments, except for a possible slight decrease in production.

Assuming a maximum water consumption in dairy cattle of 3 to 4 times the dry matter intake (NRC 1971a[205]), the concentration of nitrate to be tolerated in the water should be about one-fourth of that tolerated in the feed. This would be about 300 mg/l of NO_3N.

Gwatkin and Plummer (1946)[160] drenched pigs with potassium nitrate solutions, finding that it required in excess of 300 mg NO_3N/kg of body weight to cause erosion and hemorrhage of the gastric mucosa and subsequent death. Lower levels of this salt had no effect when administered daily for 30 days. Losses in swine due to methoglobinemia have occurred only with the consumption of preformed nitrite and not with nitrate (McIntosh et al. 1943,[192] Gwatkin and Plummer 1946,[160] Winks et al. 1950[265]). Nitrate administered orally as a single dose was found to be acutely toxic at 13 mg NO_2N/kg of body weight, 8.7 mg/kg of body weight producing moderate methemoglobinemia (Winks et al. 1950).[265] Emerick et al. (1965)[144] produced moderate methemoglobinemia in pigs with intravenous injections of 6.0 mg NO_2N/kg of body weight and found that the animals under one week of age were no more susceptible to poisoning than older ones.

Drinking water containing 330 mg/l NO_3N fed continuously to growing pigs and to gilts from weaning through two farrowing seasons had no adverse effects (Seerley et al. 1965).[242] Further, 100 mg/l of NO_2N in drinking water had no effect on performance or liver vitamin A values of pigs over a 105-day experimental period, and methemoglobin values remained low. This level of nitrite greatly exceeded the maximum of 13 mg/l NO_2N found to form in waters in galvanized watering equipment and in the presence of considerable organic matter containing up to 300 mg/l NO_3N.

In special situations involving the presence of high levels of nitrates in aqueous slurries of plant or animal tissues, nitrite accumulation reached a peak of about one-fourth to one-half the initial nitrate concentration (McIntosh et al. 1943,[192] Winks et al. 1950,[265] Barnett 1952).[109] This situation was unusual, but since wet mixtures are sometimes used for swine, it must be considered in establishing criteria for water.

Levels of nitrate up to 300 mg/l NO_3N or of nitrite up to 200 mg/l of NO_2N were added to drinking waters without adverse effects on the growth of chicks or production of laying hens (Adams et al. 1966).[104] At 200 mg/l NO_2N, nitrite decreased growth in turkey poults and reduced the liver storage of vitamin A in chicks, laying hens, and turkeys. At 50 mg/l NO_2N, no effects were observed on any of the birds. Kienholz et al. (1966)[179] found that 150 mg/l of NO_3N in the drinking water or in the feed of chicks or poults had no detrimental effect on growth, feed efficiency, methemoglobin level, or thyroid weight, while Sell and Roberts (1963)[243] found that 0.12 per cent (1,200 ppm) of NO_2N in chick diets lowered vitamin A stores in the liver and caused hypertrophy of the thyroid. Other studies have shown poultry to tolerate levels of nitrate or nitrite similar to or greater than those mentioned above (Adams et al. 1967,[105] Crawford et al. 1969[129]). Up to 450 mg/l of NO_3N in the drinking water of turkeys did not significantly affect meat color (Mugler et al. 1970).[199]

Some have suggested that nitrate or nitrite can cause a chronic or subclinical toxicity (Simon et al. 1959,[247] McIlwain and Schipper 1963,[191] Pfander 1961,[221] Beeson 1964,[111] Case 1957[125]). Some degree of thyroid hypertrophy may occur in some species with the consumption of subtoxic levels of nitrate or nitrite (Bloomfield et al. 1961,[117] Sell and Roberts 1963),[243] but possibly not in all (Jainudeen et al. 1965).[175] In the human newborn, a chronic type of methemoglobinemia may result from feeding waters of low NO_3N content (Armstrong et al. 1958).[107] It appears, however, that all classes of livestock and poultry that have been studied under controlled experimental conditions can tolerate the continued ingestion of waters containing up to 300 mg/l of NO_3N or 100 mg/l of NO_2N.

Recommendation

In order to provide a reasonable margin of safety to allow for unusual situations such as extremely high water intake or nitrite formation in slurries, the NO_3N plus NO_2N content in drinking waters for livestock and poultry should be limited to 100 ppm or less, and the NO_2N content alone be limited to 10 ppm or less.

Selenium

Rosenfeld and Beath (1964)[227] have reviewed the problems of selenium poisoning in livestock. Of the three types of this poisoning described, the "alkali disease" syndrome required the lowest level of the element in the feed for its causation. Moxon (1937)[198] placed this level at about 5 ppm, and subsequent research confirmed this figure. Later work established that the toxicity of selenium was very similar when the element was fed as it occurs in plants, as selenomethionine or selenocystine, or as inorganic selenite or selenate (Halverson et al. 1962,[162] Rosenfeld and Beath 1964,[227] Halverson et al. 1966[163]). Ruminant animals may tolerate more as inorganic salts than do monogastric animals because of the salts' reduction to insoluble elemental form by rumen microorganisms (Butler and Peterson 1961).[121]

A study with rats (Schroeder 1967)[232] revealed that selenite, but not selenate, in the drinking water caused deaths at a level of 2 mg/l and was somewhat more toxic than selenite administered in the diet. However, the results of drenching studies with cattle and sheep (Maag and Glenn 1967)[187] indicated that selenium concentration in the water should be slight, if it is any more toxic in the same chemical form administered in the feed. If there are differences with respect to the effect of mode of ingestion on toxicity, they are probably small.

To date, no substantiated cases of selenium poisoning in livestock by waters have been reported, although some spring and irrigation waters have been found to contain over 1 mg/l of the element (Byers 1935,[122] Williams and Byers 1935,[264] Beath 1943[110]). As a rule, well, surface, and ocean waters appeared to contain less than 0.05 mg/l, usually considerably less. Byers et al. (1938)[123] explained the low selenium content as a result of precipitation of the selenite ion with ferric hydroxide. Microbial activity, however, removed either selenite or selenate from water (Abu-Erreish 1967);[103] this may be another explanation.

In addition to its toxicity, the essential role of selenium in animal nutrition (Thompson and Scott 1970)[252] must be considered. Between 0.1 and 0.2 ppm in the diet have been recommended as necessary to insure against a deficiency in poultry (Scott and Thompson 1969),[241] against white muscle disease in ruminants (Muth 1963),[201] and other diseases in other animals (Hartley and Grant 1961).[167] Selenium therapy suggests it as a requirement for livestock in general. Inorganic selenium was not incorporated into tissues to the same extent as it occurred in plant tissue (Halverson et al. 1962,[162] 1966,[163] Rosenfeld and Beath 1964[227]). It is doubtful that 0.2 ppm or less of added inorganic selenium appreciably increased the amount found in the tissue of animals ingesting it. The data of Kubota et al. (1967)[183] regarding the occurrence of selenium poisoning suggested that over a good part of the United States livestock were receiving as much as 0.5 ppm or even more of naturally occurring selenium in their diets continuous without harm to them and without accumulating levels the element in their tissues that make meats or livestc products unfit for human use.

Recommendation

It is recommended that the upper limit f selenium in livestock waters be 0.05 mg/l.

Vanadium

Vanadium has been present in surface waters in t United States in concentrations up to 0.3 mg/l, althou most of the analyses showed less than 0.05 mg/l (Kopp a Kroner 1970).[182]

Recently, vanadium was determined essential for t growing rat, physiologically required levels appearing be at or below 0.1 ppm of the diet (Schwarz and Mil 1971).[240] It became toxic to chicks when incorporated in the diet as ammonium metavanadate at concentratio over about 10 ppm of the element (Romoser et al. 1961, Nelson et al. 1962,[203] Berg 1963,[112] Hathcock et al. 1964[169] Schroeder and Balassa (1967)[233] found that when mice we allowed drinking water containing 5 mg/l of vanadium vanadyl sulfate over a life span, no toxic effects were o served, but the element did accumulate to some extent i certain organs.

Recommendation

It is recommended that the upper limit fo vanadium in drinking water for livestock be 0. mg/l.

Zinc

There are many opportunities for the contamination c waters by zinc. In some areas where it is mined, this meta has been found in natural waters in concentrations as hig as 50 mg/l. It occurs in significant amounts in effluent from certain industries. Galvanized pipes and tanks may also contribute zinc to acidic waters. In a recent survey o surface waters, most contained less than 0.05 mg/l but som exceeded 5.0 mg/l, the highest value being 42 mg/l (Durum et al. 1971).[141]

Zinc is relatively nontoxic for animals. Swine have tolerated 1,000 ppm of dietary zinc (Grimmet et al. 1937,[157] Sampson et al. 1942,[229] Lewis et al. 1957,[185] Brink et al. 1959[120]), while 2,000 ppm or more have been found to be toxic (Brink et al. 1959).[120] Similar findings have been reported for poultry (Klussendorf and Pensack 1958,[181] Johnson et al. 1962,[177] Vohra and Kratzer 1968[259]) where zinc was added to the feed. Adding 2,320 mg/l of the element to water for chickens reduced water consumption, egg production, and body weight. After zinc withdrawal there were no symptoms of toxicity in chickens (Sturkie 1956).[248] In a number of studies with ruminants, Ott et al. (1966a,[215] b,[216] c,[217] d[218]) found zinc added to diets as the oxide to be toxic, but at levels over 500 mg/kg of diet.

While an increased zinc intake reflected an increase in level of the element in the body tissues, the tendency for its accumulation was not great (Drinker et al. 1927,[140] Thompson et al. 1927,[253] Sadasivan 1951,[225] Lewis et al. 1957),[155] and tissue levels fell rapidly after zinc dosing was stopped (Drinker et al. 1927,[140] Johnson et al. 1962[177]).

Zinc is a dietary requirement of all poultry and livestock. National Research Council recommendation for poults up to eight weeks was 70 mg/kg of diet; for chicks up to eight weeks, it was 50 mg/kg of diet (NRC 1971b);[206] for swine, 50 mg/kg of diet (NRC 1968a).[202] There is no established requirement for ruminants, but zinc deficiencies were reported in cattle grazing forage with zinc contents ranging between 18 and 83 ppm (Underwood 1971).[254] There is also no established requirement for sheep, but lambs fed a purified diet containing 3 ppm of the element developed symptoms of a deficiency that were prevented by adding 15 ppm of zinc to the diet: 30 ppm was required to give maximum growth (Ott et al. 1965).[214]

Cereal grains contained on the average 30–40 ppm and protein concentrates from 20 to over 100 ppm (Davis 1966).[134] In view of this, and in view of the low order of toxicity of zinc and its requirement by animals, a limit in livestock waters of 25 mg zinc/l would have a very large margin of safety. A higher limit does not seem necessary, since there would be few instances where natural waters would carry in excess of this.

Recommendation

It is recommended that the upper limit for zinc in livestock waters be 25 mg/l.

Toxic Algae

The term "water bloom" refers to heavy scums of blue-green algae that form on waters under certain conditions. Perhaps the first report of livestock poisoning by toxic algae was that of Francis (1878)[147] who described the problem in southern Australia. Fitch et al. (1934)[146] reviewed a number of cases of algal poisoning in farm animals in Minnesota between 1882 and 1933. All were associated with certain blue-green algae often concentrated by the wind at one end of the lake. Losses in cattle, sheep, and poultry were reported. The algae were found toxic to laboratory animals on ingestion or intraperitoneal injection.

According to Gorham (1964)[155] six species of blue-green algae have been incriminated, as follows:

Nodularia spumigena
Microsystis aeruginosa
Coelosphaerium Kuetzingianum
Gloeotrichia echinulata
Anabaena flos-aquae
Aphanizomenon flos-aquae

Of the above, Gorham states that *Microcystis* and *Anabaena* have most often been blamed for serious poisonings and algal blooms consisting of one or more of these species vary considerably in their toxicity (Gorham 1964).[155] According to Gorham (1960),[154] this variability seems to depend upon a number of factors, e.g., species and strains of algae that are predominant, types and numbers of bacterial associates, the conditions of growth, collection and decomposition, the degree of animal starvation and susceptibility, and the amount consumed. To date, only one toxin from blue-green algae has been isolated and identified, only from a few species and streams. This was a cyclic polypeptide containing 10 amino acid residues, one of which was the unnatural amino acid D-serine (Bishop et al. 1959).[116] This is also referred to as FDF (fast-death factor), since it causes death more quickly than SDF (slow-death factor) toxins produced in water blooms.

Shilo (1967)[244] pointed out that the sudden decomposition of algal blooms often preceded mass mortality of fish, and similar observations were made with livestock poisonings. This suggests that the lysis of the algae may be important in the release of the toxins, but it also suggests that in some circumstances botulism may be involved. The lack of oxygen may have caused the fish kill and must also be considered.

Predeath symptoms in livestock have not been carefully observed and described. Post-mortem examination is apparently of no help in diagnosis (Fitch et al. 1934).[146] Feeding or injecting algal suspensions or water from suspect waters have been used to some extent, but the occasional fleeting toxicity of these materials makes this procedure of limited value. Identification of any of the toxic blue-green algae species in suspect waters does no more than suggest the possibility that they caused livestock deaths.

In view of the many unknowns and unresolved problems relating blooms of toxic algae, it is impossible to suggest any recommendations insuring against the occurrence of toxic algae in livestock waters.

Recommendation

The use for livestock of waters bearing heavy growths of blue green algae should be avoided.

Radionuclides

Surface and groundwaters acquire radioactivity from natural sources, from fallout resulting from atmospheric nuclear detonations, from mining or processing uranium, or as the result of the use of isotopes in medicine, scientific research, or industry.

All radiation is regarded as harmful, and any unnecessary exposure to it should be avoided. Experimental work on the biological half-lives of radionuclides and their somatic and genetic effects on animals have been briefly reviewed by McKee and Wolf (1963).[193] Because the rate of decay of a radionuclide is a physical constant that cannot be changed, radioactive isotopes must be disposed of by dilution or by storage and natural decay. In view of the variability in half-lives of the many radioisotopes, the nature of their radioactive emissions, and the differences in metabolism of various elements by different animals, the results of animal experimentation do not lend themselves easily to the development of recommendations.

Based on the recommendations of the U. S. Federal Radiation Council (1960,[257] 1961[258]), the Environmental Protection Agency will set drinking water standards for radionuclides (1972),[145] to establish the intake of radioactivity from waters that when added to the amount from all other sources will not likely be harmful to man.

Recommendation

In view of the limited knowledge of the effect of radionuclides in water on domestic animals, it is recommended that the Federal Drinking Water Standards be used for farm animals as well as for man.

PESTICIDES (IN WATER FOR LIVESTOCK)

Pesticides include a large number of organic and inorganic compounds. The United States production of synthetic organic pesticides in 1970 was 1,060 million pounds consisting almost entirely of insecticides (501 million pounds), herbicides (391 million pounds), and fungicides (168 million pounds). Production data for inorganic pesticides was limited. Based on production, acreage treated, and use patterns, insecticides and herbicides comprise the major agricultural pesticides (Fowler 1972).[279] Of these, some can be detrimental to livestock. Some have low solubility in water, but all cause problems if accidental spillage produces high concentrations in water, or if they become adsorbed on colloidal particles subsequently dispersed in water.

Insecticides are subdivided into three major classes of compounds including methylcarbamates, organophosphates and chlorinated hydrocarbons. Many of these substances produce no serious pollution hazards, because they are nonpersistent. Others, such as the chlorinated hydrocarbons, are quite persistent in the environment and are the pesticides most frequently encountered in water.

Entry of Pesticides into Water

Pesticides enter water from soil runoff, direct application, drift, rainfall, spills, or faulty waste disposal techniques. Movement by erosion of soil particles with adsorbed pesticides is one of the principal means of entry into water. The amount carried in runoff water is influenced by rates of application, soil type, vegetation, topography, and other factors. Because of strong binding of some pesticides on soil particles, water pollution by pesticides is thought to occur largely through the transport of chemicals adsorbed to soil particles (Lichtenstein et al. 1966).[281] This mechanism r not always be a major route. Bradley et al. (1972)[269] served that when 13.4 kg/hectare DDT and 26.8 kg/hec toxophene were applied to cotton fields, only 1.3 and (per cent, respectively, of the amounts applied were detec in natural runoff water over an 8-month period.

Pesticides can also enter the aquatic environment by di: application to surface waters. Generally, this use is to c trol mosquito larvae, nuisance aquatic weeds, and, as several southern states, to control selected aquatic fa such as snails (Chesters and Konrad 1971).[271] Both of tl pathways generally result in contamination of surface wa rather than groundwaters.

Precipitation, accidental spills, and faulty waste dispo are less important entry routes. Pesticides detected in ra water include DDT, DDD, DDE, dieldrin, alpha-BHC a gamma-BHC in extremely minute concentrations (i.e., the order of 10^{-12} parts or the nanograms per liter le (Weibel et al. 1966,[295] Cohen and Pinkerton 1966,[274] T rant and Tatton 1968[291]). Spills and faulty waste dispo techniques are usually responsible for short-term, high-le contamination.

The amount of pesticide actually in solution, howev is governed by a number of factors, the most importa probably being the solubility of the molecule. Chlorinat hydrocarbon insecticides, for example, have low solubil in water (Freshwater Appendix II-D). Cationic pesticic (i.e., paraquat and diquat) are rapidly and tightly bou to soil particles and are inactivated (Weed Society America 1970).[294] Most arsenical pesticides form insolul salts and are inactivated (Woolson et al. 1971).[297] A surv of the water and soil layers in farm ponds indicates high concentrates of pesticides are associated with the soil laye that interface with water than in the water *per se*. In an e tensive survey of farm water sources (U. S. Dept. of Agi culture, Agricultural Research Service 1969a,[292] hereaft referred to as Agriculture Research Service 1969a[292] analysis of sediment showed residues in the magnitude (decimal fractions of a microgram per gram (μg/g) to a hig of 4.90 μg/g DDT and its DDE and DDD degradatio compounds. These were the principal pesticides found i sediment. Dieldrin and endrin were also detected in sedi ment in two study areas where surface drainage wate entered farm ponds from an adjacent field.

Pesticides Occurrence in Water

Chlorinated hydrocarbon insecticides are the pesticide most frequently encountered in water. They include DDT and its degradation products DDE and DDD, dieldrin, endrin, chlordane, aldrin, and lindane. In a pesticide monitoring program conducted from 1957 to 1965, Breidenbach et al. (1967)[270] concluded that dieldrin was present in all sampled river basins at levels from 1 to 22 nanograms (ng)/liter. DDT and its metabolites were found to occur in most surface waters, while levels of endrin in the lower

Mississippi decreased from a high of 214 ng/l in 1963 to a range of 15 to 116 ng/l in 1965. Results of monitoring studies conducted by the U. S. Department of Agriculture (Agricultural Research Service 1969a)[267] from 1965 to 1967 indicated that only very small amounts of pesticides were present in any of the sources sampled. The most prevalent pesticides in water were DDT, its metabolites DDD and DDE, and dieldrin. Levels detected were usually below one part per billion. The DDT family, dieldrin, endrin, chlordane, lindane, heptachlor epoxide, trifluralin, and 2,4-D, were detected in the range of 0.1 to 0.01 μg/l. In a major survey of surface waters in the United States conducted from 1965 to 1968 for chlorinated hydrocarbon pesticides (Lichtenberg et al. 1969),[282] dieldrin and DDT (including DDE and DDD) were the compounds most frequently detected throughout the 5-year period. After reaching a peak in 1966, the total number of occurrences of all chlorinated hydrocarbon pesticides decreased sharply in 1967 and 1968.

A list of pesticides most likely to occur in the environment and, consequently, recommended for inclusion in monitoring studies, was developed by the former Federal Committee on Pesticide Control (now Working Group on Pesticides). This list was revised (Schechter 1971)[290] and expanded to include those compounds (1) whose persistence is of relatively long-term duration; (2) whose use patterns is large scale in terms of acreage; or (3) whose inherent toxicity is hazardous enough to merit close surveillance. The primary list includes 32 pesticides or classes of pesticides (i.e. arsenical pesticides, mercurial pesticides, and several dithiocarbamate fungicides) recommended to be monitored in water. A secondary list of 17 compounds was developed for consideration, if monitoring activities are expanded in the future. The pesticides found on the primary list would be those most likely to be encountered in farm water supplies (see Freshwater Appendix II-D).

Toxicological Effects of Pesticides on Livestock

Mammals generally have a greater tolerance to pesticides than birds and fish. However, the increased use of pesticides in agriculture, particularly the insecticides, presents a potential hazard to livestock. Some compounds such as the organophosphorous insecticides can be extremely dangerous, especially when mishandled or wrongly used. To date, however, there actually have been very few verified cases of livestock poisoning from pesticides (Papworth 1967).[287] In the few instances reported, the cause of livestock poisoning usually has been attributed to human negligence. For livestock, pesticide classes that may pose possible hazards are the acaricides, fungicides, herbicides, insecticides, molluscides, and rodenticides (Papworth 1967).[287]

Acaricides intended for use on crops and trees usually have low toxicity to livestock. Some, such as technical chlorobenzilate, have significant toxicity for mammals. The acute oral LD50 in rats is 0.7 g/kg of body weight (Papworth 1967).[287] With fungicides, the main hazard to livestock apparently is not from the water route, but from their use as seed dressings for grain. Of the types used, the organomercury compounds and thiram are potentially the most dangerous (McEntee 1950,[283] Weibel et al. 1966[295]). The use of all organomercury fungicides is restricted by the Environmental Protection Agency (Office of Pesticides, Pesticides Regulation Division 1972).[277] Consequently, the possible hazard to livestock from these compounds has, for most purposes, been eliminated.

Of the herbicides in current use, the dinitro compounds pose the greatest hazard to livestock. Dinitroorthocresol (DNC or DNOC) is probably the most used member of this group. In ruminants, however, DNC is destroyed rapidly by the rumen organisms (Papworth 1967).[287] These compounds are very persistent, up to two years, and for livestock the greatest hazard is from spillages, contamination of vegetation, or water. In contrast, the phenoxyacetic acid derivatives (2,4-D, MCPA) are comparatively harmless. Fertig (1953)[278] states that suspected poisoning of livestock or wildlife by phenoxy herbicides could not be substantiated in all cases carefully surveyed. The hazards to livestock from hormone weed killers are discussed by Rowe and Hymas (1955),[289] and dinitrocompounds by McGirr and Papworth (1953)[284] and Edson (1954).[276] The possible hazards from other herbicides are reviewed by Papworth (1967)[287] and Radeleff (1970).[288]

Of the classes of insecticides in use, some pose a potential hazard to livestock, while others do not. Insecticides of vegetable origin such as pyrethrins and rotenones, are practically non-toxic to livestock. Most chlorinated hydrocarbons are not highly toxic to livestock, and none is known to accumulate in vital organs. DDT, DDD, dilan, methoxychlor, and perthane are not highly toxic to mammals, but some other chlorinated hydrocarbons are quite toxic (Papworth 1967,[287] Radeleff 1970[288]). The insecticides that are potentially the most hazardous are the organophosphorus compounds causing chlorinesterase inhibition. Some, such as mipafax, induce pathological changes not directly related to cholinesterase inhibition (Barnes and Denz 1953).[268] Liquid organophosphorus insecticides are absorbed by all routes, and the lethal dose for most of these compounds is low (Papworth 1967,[287] Radeleff 1970[288]).

Pesticides in Drinking Water for Livestock

The subgroup on contamination in the Report of the Secretary's Commission on Pesticides and Their Relationship to Environmental Health (U.S. Dept. of Health, Education, and Welfare 1969)[293] examined the present knowledge on mechanisms for dissemination of pesticides in the environment, including the water route. There have been no reported cases of livestock toxicity resulting from pesticides in water. However, they conclude that the possibility of contamination and toxicity from pesticides is real because of indiscriminate, uncontrolled and excessive use.

Pesticide residues in farm water supplies for livestock and related enterprises are undesirable and must be reduced or eliminated whenever possible. The primary problem of reducing levels of pesticides in water is to locate the source of contamination. Once located, appropriate steps should be taken to eliminate the source.

Some of the properties and concentrations of pesticides found in water are shown in Table V-4. Although many pesticides are readily broken down and eliminated by livestock with no subsequent toxicological effect, the inherent problems associated with pesticide use include the accumulation and secretion of either the parent compound or its degradation products in edible tissues and milk (Kutches et al. 1970).[280] Consequently, pesticides consumed by livestock through drinking water may result in residues in fat and certain produce (milk, eggs, wool), depending on the level of exposure and the nature of the pesticide. There is also a possibility of interactions between insecticides and drugs, especially in animal feeds (Conney and Hitchings 1969).[275]

Nonpolar lipophilic pesticides such as the chlorinated hydrocarbon insecticides (DDT, lindane, endrin, and others) tend to accumulate in fatty tissue and may result in measurable residues. Polar, water soluble pesticides and their metabolic derivatives are generally excreted in the urine soon after ingestion. Examples of this class would include most of the phosphate insecticides and the acid herbicides (2,4-D; 2,4,5-T; and others). Approximately 96 per cent of a dose of 2,4-D fed to sheep was excreted unchanged in the urine and 1.4 per cent in the feces in 72 hours (Clark et al. 1964).[273] Feeding studies (Claborn et al. 1960)[272] have shown that when insecticides were fed to beef cattle and sheep as a contaminant in their feed at dosages that occur as residues on forage crops, all except methoxychlor were stored in the fat. The levels of these insecticides in fat decreased after the insecticides were removed from the animals' diets. When poultry were exposed to pesticides either by ingestion of contaminated food or through the use of pesticides in poultry houses, Whitehead (1971)[296] observed that the toxicities to birds of the substance
varied greatly. However, nonlethal doses may affect g
rate, feed conversion efficiency, egg production, eg
shell thickness, and viability of the young. Although
fects of large doses may be considerable, Whiteheac
cluded that little is known about the impairment of p
tion at low rates commonly used in agricultural prac

TABLE V-4—Some Properties, Criteria, and Concentrations of Pesticides Found in Water

	Solubility μg/liter	Toxicity LD50 mg/kg	Maximum concentration[a] μg/l
aldrin	....	38	0.085
dieldrin	110	46	0.407
endrin	160	10	0.133
heptachlor	56	130	0.048
heptachlor epoxide	350	....	0.067
DDT	1.2	113	0.316
DDE	....	....	0.050
DDD	....	....	0.840
2,4-D[b]	60,000	300–1000	

[a] Maximum concentration of pesticide found in surface waters in the United States, from Lichtenberg et al. (1969)[287].

[b] Refers to the herbicide family 2,4-D; 2,4,5-T; and 2,4,5-TP.

Elimination of fat soluble pesticides from contam
animals is slow. Urinary excretion is insignifican
elimination in feces is slow. The primary route of exc
in a lactating animal is through milk. The lowest conc
tions of pesticides in feeds that lead to detectable resic
animal tissues or products exceed the amounts fou
water by a factor of 10,000. However, at the compar
high dosage rates given in feeds, certain trends are app
Cows fed DDT in their diet at rates of 0.5, 1.0, 2.0, 3.
5.0 mg/kg exhibited residues in milk at all feeding
except at 0.5 mg/kg. As the DDT feed levels incr
contamination increased (Zweig et al. 1961).[298] Wher
were removed from contaminated feeds, the amou
time required for several pesticides to reach the non-c
able level was recorded (Moubry et al. 1968).[286] Di
had the longest retention time in milk, approximate
days. DDT and its analogs, BHC, lindane, endrin
methoxychlor followed in that order. It should be er
sized that levels found in farm water supplies do not m
significant contribution to animal body burdens of pes
compared to amounts accumulated in feeds.

Table V-4 shows the toxicity of some important
cides. Assuming the average concentration of any pes
in water is 0.1 μg/l, and the average daily consumpt
water by dairy or beef cattle is 60 liters per day, the
average daily intake of DDT would be 0.006 mg. Fu
assuming that the average body weight for dairy or be
tle is 450 kg and the LD50 for DDT is 113 mg/kg (
V-4), then 50 grams would have to be consumed to app
the dose that would be lethal to 50 per cent of the anim
a steer were maintained on this water for 1,000 days, t
would have ingested about 1/10,000 of the reported I
For endrin (LD50 = 10 mg/kg), cattle would ingest 1
of the established LD50. The safety margin is pro
greater than indicated, because the calculations assum
all of the insecticide is retained unaltered during the
ingestion period. DDT is known to be degraded to a li
extent by bovine rumen fluid and by rumen microo
isms. For sheep, swine, horses, and poultry, the av
daily water intake in liters is about 5, 10, 40, and 0.
spectively. Consequently, their intake would be substan
less.

Fish as Indicators of Water Safety

The presence of fish may be an excellent monito
toxic levels of pesticides in livestock water supplies. T
are numerous and well documented examples in the li
ture of the biological magnification of persistent pesti

TABLE V-5—Examples of Fish as Indicators of Water Safety for Livestock

Material	Toxic-levels mg/l for fish	Toxic effects on animals
Aldrin	0.02	3 mg/kg food (poultry).
Chlordane	1.0 (sunfish)	91 mg/kg body weight in food (cattle).
Dieldrin	0.025 (trout)	25 mg/kg food (rats).
Dipterex	50.0	10.0 mg/kg body weight in food (calves).
Endrin	0.003 (bass)	3.5 mg/kg body weight in food (chicks).
Ferban, fermate	1.0 to 4.0	
Methoxychlor	0.2 (bass)	14 mg/kg alfalfa hay, not toxic (cattle).
Parathion	2.0 (goldfish)	75 mg/kg body weight in food (cattle).
Pentachlorophenol	0.35 (bluegill)	60 mg/l drinking water not toxic (cattle).
Pyrethrum (allethrin)	2.0 to 10.0	1,400 to 2,800 mg/kg body weight in food (rats).
Silvex	5.0	500 to 2,000 mg/kg body weight in food (chicks).
Toxaphene	0.1 (bass)	35 to 110 mg/kg body weight in food (cattle).

McKee and Wolf, 1963[285].

by fish and other aquatic organisms (See Sections III and IV on Freshwater and Marine Aquatic Life and Wildlife.) Because of the lower tolerance levels of these aquatic organisms for persistent pesticides such as chlorinated hydrocarbon insecticides, mercurial compounds, and heavy metal fungicides, the presence of living fish in agricultural water supplies would indicate their safety for livestock (McKee and Wolf 1963).[285] Some examples of individual effects of pesticides upon fish compared to animal species are shown in Table V-5. These data indicate that fish generally have much lower tolerance for commonly used pesticides than do livestock and poultry.

Recommendation

Feeding studies indicate no deleterious effects of reported pesticide residues in livestock drinking water on animal health. To prevent unacceptable residues in animal products, the maximum levels proposed in the pesticide section of the Panel of Public Water Supplies are recommended for farm animal water supplies.

PATHOGENS AND PARASITIC ORGANISMS

Microbial Pathogens

One of the most significant factors in the spread of infectious diseases of domesticated animals is the quality of water which they consume. In many instances the only water available to livestock is from surface sources such as ponds, waterholes, lakes, rivers and creeks. Not infrequently these sources are contaminated by animals which wade to drink or stand in them seeking refuge from pests. Contamination with potential disease-producing organisms comes from surface drainage originating in corrals, feed lots, or pastures in which either sick or carrier animals are kept.

Direct evidence relating the occurence of animal pathogens in surface waters and disease outbreaks is limited. However, water may be a source for listeriosis caused by *Listeria monocytogenes* (Larsen 1964)[302] and erysipelas caused by *Erysipelothrix rhusiopathiae* (Wood and Packer in press 1972).[310] Tularemia of animals is not normally waterborne, but the organism *Pasteurella tularensis* has been isolated from waters in the United States (Parker et al. 1951,[303] Seghetti 1952).[305] Enteric microorganisms, including the vibrios (Wilson and Miles 1966)[309] and amoebae, have a long record as water polluting agents.

The *Escherichia-Enterobacter-Klebsiella* group of enterics are widely distributed in feed, water, and the general environment (Breed et al. 1957).[299] They sometimes cause urinary disease, abscesses, and mastitis in livestock. *Salmonella* are very invasive and the carrier state is easily produced and persistent, often without any general evidence of disease. Spread of the enterics outside the yards, pens, or pastures of infected livestock is a possibility, but the epidemiology and ecology of this problem are not clear.

In the United States, leptospirosis is probably the most intimately water-related disease problem (Gillespie et al. 1957,[301] Crawford et al. 1969[300]). The pathogenic leptospira leave the infected host through urine and lack protection against drying. Direct animal-to-animal spread can occur through urine splashed to the eyes and nostrils of another animal.

Infection by leptospirosis from water often is direct: that is, contaminated water infects animals that consume it or come into contact with it.

Van Thiel (1948)[308] and Gillespie et al. (1957)[301] pointed out that mineral composition and pH of water are factors affecting continued mobility of voided leptospira. Most episodes of leptospirosis can be traced to ponds, ricefields, and natural waters of suitable pH and mineral composition. For leptospira control, livestock must not be allowed to wade in contaminated water. Indirect contamination of water through sewage is unlikely, although free-living leptospira may occur in such an environment.

The Genus *Clostridium* is comprised of many species (Breed et al. 1957),[299] some of which have no pathogenic characteristics. Some such as *Clostridium perfrigens* and *Cl. tetani* may become adapted to an enteric existence in animals. Almost all of them are soil adapted. Water has a vital role in environments favorable for anaerobic infections caused by *Clostridia*.

Management of water to avoid oxygen depletion serves to control the anaerobic problem. Temporary or permanent areas of anaerobic water environment are dangerous to livestock. Domestic animals should be prevented from consuming water not adequately oxygenated.

One of the best examples of water-related disease is bacillary hemoglobinuria, caused by an organism *Cl. hemolyticum* found in western areas of North and South America. It has been linked with liver fluke injury, but is not dependent on the presence of flukes. Of particular concern has been the spread of this disease to new areas in the western states. As described by Van Ness and Erickson (1964),[307] each new premise is an endemic area which has an alkaline, anaerobic soil-water environment suitable for the organism. This disease has made its appearance in new areas of the West when these areas are cleared of brush and irrigated. To avoid this problem, western irrigation waters should be managed to avoid cattail marshes, hummock grasses, and other environments of prolonged saturation.

Anthrax in livestock is a disease of considerable concern. The organism causing anthrax, *Bacillus anthracis*, may occur in soils with pH above 6.0. The organism forms spores which, in the presence of adequate soil nutrients, vegetate and grow. The spread of disease by drinking water containing spores has never been proved. Bits of hide and hair waste may be floated by water downstream from manufacturing plants, but very few outbreaks have been reported from these sources. The disease is associated with the water from pastures where the grass has been killed (Van Ness 1971).[306] The killed grass is brown rather than blackened, a significant difference from water drowned vegetation in general.

The epidemiology of virus infections tends to incriminate direct contact: e.g., fomites, mechanical, and biological vectors, but seldom water supplies. Water used to wash away manure prior to the use of disinfectants or other biological control procedure may carry viruses to the general environment.

Viruses are classified by size, type of nucleic acid, structure, ether sensitivity, tissue effects (which includes viruses long known to cause recognizable diseases, such as pox and hog cholera), and by other criteria. Only the ether-resistant viruses, such as those causing polio and foot and mouth disease in cattle, appear to present problems in natural water (Prier 1966).[304]

Parasitic Organisms

Parasitic protozoa include numerous forms which are capable of causing serious livestock losses. Most outbreaks follow direct spread among animals. Water contaminated with these organisms or their cysts becomes an indirect factor in spread of infection.

Some of the most important parasitic forms are the various flukes which develop as adult forms in man and livestock. Important ecological factors include presence of snails and vegetation in the water, or vegetation covered by intermittent overflow. This problem is very serious in irrigated a but only when snails or other intermediate hosts are a able for the complete life cycle. Fluke eggs passed by host, usually in the manure (some species, in the ur enter the water and hatch into *miracidia*. These seek o snail or other invertebrate host where they develop *sporocysts*. These transform into redia which in turn form other redia or several *cercariae*. The cercariae leave snail and swim about the water where they may find final host, or may encyst on vegetation to be eaten l The life cycle is completed by maturing in a suitable and establishment of an exit for eggs from the site of th tachment.

Roundworms include numerous species which may water pathways in their life cycle. Free-living nemat can sometimes be found in a piped water supply, but probably of little health significance. Moisture is an portant factor in the life cycle of many parasitic roundwo and livestock are maintained in an environment where tamination of water supplies frequently occurs. It is usu thought that roundworm eggs are eaten but water-satur environments provide ideal conditions for maintaining p lations of these organisms and their eggs.

Parasitic roundworms probably evolved through ev tionary cycles exemplified by the behavior of the g *Strongyloides*. *Strongyloides* spread along drainageways thro the washdown of concrete feeding platforms and o housing facilities for livestock.

The Guinea worm, *Dracunculus*, is dependent upon wa because the adult lays eggs only when the host come contact with water. Man, dogs, cats, or various wild m mals may harbor the adult, and the larvae develop *Cyclops*. The life cycle is thus maintained in a water envi ment when the *Cyclops* is swallowed by another suitable h

Eggs of "horsehair worms" are laid by the adult in w or moist soil. The larvae encyst and if eaten by an appro ate insect will continue development to the adult st Worms do not leave the insect unless they can enter wa

The prevention of water-borne diseases and parasit in domestic animals depends on interruption of the o nisms' life cycle. The most effective means is to keep l stock out of contaminated water. Treatment for the rem of the pathogen or parasite from the host and destructio the intermediate host are measures of control.

WATER FOR IRRIGATION

Irrigation farming increases productivity of croplands and provides flexibility in alternating crops to meet market demands. Early irrigation developments in the arid and semiarid West were largely along streams where only a small part of the total annual flow was put to use. Such streams contained dissolved solids accumulated through the normal leaching and weathering processes with only slight additions or increases in concentrations resulting from man's activities. Additional uses of water resources have in many cases concentrated the existing dissolved solids, added new salts, contributed toxic elements, microbiologically polluted the streams, or in some other way degraded the quality of the water for irrigation. Water quality criteria for irrigation has become increasingly significant as new developments in water resources occur.

Soil, plant, and climate variables and interactions must be considered in developing criteria for evaluation of irrigation water quality. A wide range of suitable water characteristics is possible even when only a few variables are considered. These variables are important in determining the quality of water that can be used for irrigation under specific conditions.

The physicochemical properties of a soil determine the root environment that a plant encounters following irrigation. The soil consists of an organo-mineral complex that has the ability to react both physically and chemically with constituents present in irrigation water. The degree to which these added constituents will leach out of a soil, remain available to plants in the soil, or become fixed and unavailable to plants, depends largely on the soil characteristics.

Evapotranspiration by plants removes water from the soil leaving the salts behind. Since uptake by plants is negligible, salts accumulate in the soil in arid and semiarid areas. A favorable salt balance in the root zone can be maintained by leaching, through the use of irrigation water in excess of plant needs. Good drainage is essential to prevent a rising water table and salt accumulation in the soil surface and to maintain adequate soil aeration.

In irrigated areas, a water frequently exists at some depth below the ground surface, with an unsaturated condition existing above it. During and immediately following periods of precipitation or irrigation, water moves downward through the soil to the water table. At other times, water is lost through evaporation from the soil surface, and transpiration from plants (evapotranspiration) may reverse the direction of flow in the soil, so that water moves upward from the water table by capillary flow. The rate of movement is dependent upon water content, soil texture, and structure. In humid and subhumid regions, this capillary rise of water in the soil is a valuable water source for use by crops during periods of drought.

Even under favorable conditions of soil, drainage, and environmental factors, too sparing applications of high quality water with total dissolved solids of less than 100 mg/l would ultimately damage sensitive crops such as citrus fruit; whereas with adequate leaching, waters containing 500 to 1,000 mg/l might be used safely. Under the same conditions, certain salt-tolerant field crops might produce economic returns using water with more than 4,000 mg/l. Criteria for judging water quality must take these factors into account.

The need for irrigation for optimum plant growth is determined also by rainfall and snow distribution; and by temperature, radiation, and humidity. Irrigation must be used for intensive crop production in arid and semiarid areas and must supplement rainfall in humid areas. (See Specific Irrigation Water Considerations below.)

The effects of water quality characteristics on soils and on plant growth are directly related to the frequency and amount of irrigation water applied. The rate at which water is lost from soils through evapotranspiration is a direct function of temperature, solar radiation, wind, and humidity. Soil and plant characteristics also influence this water loss. Aside from water loss considerations, water stress in a plant, as affected by the rate of evapotranspiration, will determine the plant's reaction to a given soil condition. For example, in a saline soil at a given water content, a plant will usually suffer more in a hot, dry climate than in a cool, humid one. Considering the wide variation in the climatic and soil variables over the United States, it is apparent that water quality requirements also vary considerably.

Successful sustained irrigated agriculture, whether in arid regions or in subhumid regions, or other areas, requires skillful water application based upon the characteristics of the land, water, and the requirements of the crop. Through proper timing and adjustment of frequency and volumes of water applied, detrimental effects of poor quality water may often be mitigated.

WATER QUALITY CONSIDERATIONS FOR IRRIGATION

Effects on Plant Growth

Plants may be adversely affected directly by either the development of high osmotic conditions in the plant substrate or by the presence of a phytotoxic constituent in the water. In general, plants are more susceptible to injury from dissolved constituents during germination and early growth than at maturity (Bernstein and Hayward 1958).[315] Plants affected during early growth may result in complete crop failure or severe yield reductions. Effects of undesirable constituents may be manifested in suppressed vegetative growth, reduced fruit development, impaired quality of the marketable product, or a combination of these factors. The presence of sediment, pesticides, or pathogenic organisms in irrigation water, which may not specifically affect plant growth, can affect the acceptability of the product. Another aspect to be considered is the presence of elements in irrigation water that are not detrimental to crop production but may accumulate in crops to levels that may be harmful to animals or humans.

Where sprinkler irrigation is used, foliar absorption or adsorption of constituents in the water may be detrimental to plant growth or to the consumption of affected plants by man or animals. Where surface or sprinkler irrigation is practiced, the effect of a given water quality on plant growth is determined by the composition of the soil solution. This is the growth medium available to roots after soil and water have reacted.

Plant growth may be affected indirectly through the influence of water quality on soil. For example, the absorption by the soil of sodium from water will result in a dispersion of the clay fraction. The degree of dispersion will depend on the clay minerals present. This decreases soil permeability and often results in a surface crust formation that deters seed germination and emergence. Soils irrigated with highly saline water will tend to be flocculated and have relatively high infiltration rates (Bower and Wilcox 1965).[316] A change to waters of sufficiently lower salt content reduces soil permeability and rates of infiltration by dispersion of the clay fraction in the soil. This hazard increases when combined with high sodium content in the water. Much depends upon whether a given irrigation water is used continuously or occasionally.

Crop Tolerance to Salinity

The effect of salinity, or total dissolved solids, on the osmotic pressure of the soil solution is one of the most important water quality considerations. This relates t
availability of water for plant consumption. Plants
been observed to wilt in fields apparently having ade
water content. This is usually the result of high soil sa
creating a physiological drought condition. Specificall
ability of a plant to extract water from a soil is deterr
by the following relationship:

$$TSS = MS + SS$$

In this equation, (U.S. Department of Agriculture, Sa
Laboratory Staff 1954[337] hereafter referred to as Sa
Laboratory 1954[335]) the total soil suction (TSS) repr
the force with which water in the soil is withheld from
uptake. In simplified form, this factor is the sum c
matric suction (MS) or the physical attraction of so
water, and the solute suction (SS) or the osmotic pre
of the soil water.

As the water content of the soil decreases due to ev
transpiration, the water film surrounding the soil par
becomes thinner and the remaining water is held wit
creasingly greater force (MS). Since only pure wat
lost to the atmosphere during evapotranspiration, th
concentration of soil solution increases rapidly d
the drying process. Since the matric suction of a soi
creases exponentially on drying, the combined effec
these two factors can produce critical conditions wit
gard to soil water availability.

In assessing the problem of plant growth, the sal
level of the soil solution must be evaluated. It is difficu
extract the soil solution from a moist soil within the ran
water content available to plants. It has been demonstra
however, that salinity levels of the soil solution and
resultant effects upon plant growth may be correlated
salinity levels of soil moisture at saturation. The quanti
water held in the soil between field capacity and the wi
point varies considerably from relatively low values
sandy soils to high values for soils high in clay content

The U.S. Salinity Laboratory Staff (1954)[335] develo
the technique of using a saturation extract to meet
need. Demineralized water is added to a soil sample
point at which the soil paste glistens as it reflects light
flows slightly when the container is tipped. The amoun
water added is reasonably related to the soil texture.
many soils, the water content of the soil paste is roug
twice that of the soil at field capacity and four times tha
the wilting point. This water content is called the saturat
percentage. When the saturated paste is filtered, the res
ant solution is referred to as the saturation extract. The
content of the saturation extract does not give an ex
indication of salinity in the soil solution under field con
tions, because soil structure has been destroyed; nor doe
give a true picture of salinity gradients within the soil res
ing from water extraction by roots. Although not truly
picting salinity in the immediate root environment, it d
give a usable parameter that represents a soil salinity va
that can be correlated with plant growth.

TABLE V-6—Relative Tolerance of Crop Plants to Salt, (Listed in Decreasing Order of Tolerance[a])

High salt tolerance	Medium salt tolerance	Low salt tolerance
	VEGETABLE CROPS	
$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 4$
Garden beets	Tomato	Radish
Kale	Broccoli	Celery
Asparagus	Cabbage	Green beans
Spinach	Bell pepper	
	Cauliflower	
	Lettuce	
	Sweet corn	
	Potatoes (White Rose)	
	Carrot	
	Onion	
	Peas	
	Squash	
	Cucumber	
$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 4$	$EC_e \times 10^3 = 3$
	FIELD CROPS	
$EC_e \times 10^3 = 16$	$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 4$
Barley (grain)	Rye (grain)	Field beans
Sugar beet	Wheat (grain)	
Rape	Oats (grain)	
Cotton	Rice	
	Sorghum (grain)	
	Corn (field)	
	Flax	
	Sunflower	
	Castorbeans	
$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 6$	
	FRUIT CROPS	
Date palm	Pomegranate	Pear
	Fig	Apple
	Olive	Orange
	Grape	Grapefruit
	Cantaloupe	Prune
		Plum
		Almond
		Apricot
		Peach
		Strawberry
		Lemon
		Avocado
	FORAGE CROPS (in decreasing order tolerance)	
$EC_e \times 10^3 = 18$	$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 4$
Alkali sacaton	White sweet clover	White Dutch clover
Saltgrass	Yellow sweet clover	Meadow foxtail
Nuttall alkaligrass	Perennial ryegrass	Alsike clover
Bermuda grass	Mountain brome	Red clover
Rhodes grass	Strawberry clover	Ladino clover
Rescue grass	Dallis grass	Burnet
Canada wildrye	Sudan grass	
Western wheatgrass	Hubam clover	
Barley (hay)	Alfalfa (California common)	
Bridsfoot trefoil	Tall fescue	
	Rye (hay)	
	Wheat (hay)	
	Oats (hay)	
	Orchardgrass	
	Blue grama	
	Meadow fescue	
	Reed canary	
	Big trefoil	
	Smooth brome	
	Tall meadow oatgrass	
	Cicer milkvetch	
	Sourclover	
	Sickle milkvetch	
$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 4$	$EC_e \times 10^3 = 2$

[a] The numbers following $EC_e \times 10^3$ are the electrical conductivity values of the saturation extract in millimhos per centimeter at 25 C associated with 50-per cent decrease in yield.

Salinity Laboratory Staff 1954[335].

Salinity is most readily measured by determining the electrical conductivity (EC) of a solution. This method relates to the ability of salts in solution to conduct electricity and results are expressed as millimhos $(\text{mhos} \times 10^{-3})$ per centimeter (cm) at 25 C. Salinity of irrigation water is expressed in terms of EC, and soil salinity is indicated by the electrical conductivity of the saturation extract (EC_e). See Table V-6.

Temperature and wind effects are especially important as they directly affect evapotranspiration. Periods of high temperature or other factors such as dry winds, which increase evapotranspiration rates, not only tend to increase soil salinity but also create a greater water stress in the plant. The effect of climate conditions on plant response to salinity was demonstrated by Magistad and his associates (1943).[324] Some of these effects can be alleviated by more frequent irrigation to maintain safer levels of soil salinity.

Plants vary in their tolerance to soil salinity, and there are many ways in which salt tolerance can be appraised. Hayward and Bernstein (1958)[321] point out three: (1) Test the ability of a plant to survive on saline soils. Salt tolerance based primarily on this criterion of survival has limited application in irrigation agriculture but is a method of appraisal that has been used widely by ecologists. (2) Test the absolute yield of a plant on a saline soil. This criterion has the greatest agronomic significance. (3) Relate the yield on saline soil to nonsaline soil. This criterion is useful for comparing dissimilar crops whose absolute yields cannot be compared directly.

The U. S. Salinity Laboratory Staff (1954)[335] has used the third criterion in establishing the list of salt tolerance of various crops shown in Table V-6. These salt tolerance values are based upon the conductivity of the saturation extract (EC_e) expressed in mmhos/cm at which a 50 per cent decrement in yield may be expected when compared to

TABLE V-7—Soil Salinities in Root Zone at which Yield Reductions become Significant

Crop	Electrical conductivity of saturation extracts (EC_e) at which yields decrease by about 10 per cent[a]
	mmh/cm at 25 C
Date palm	8
Pomegranate Fig Olive	4–6[b]
Grape	4
Muskmelon	3.5
Orange, grapefruit, lemon[c]	3–2.5
Apple, pear	2.5
Plum, prune, peach, apricot, almond	2.5
Boysenberry, blackberry, raspberry[c]	2.5–1.5
Avocado	2
Strawberry	1.5

[a] In gypsiferous soils, EC_e readings for given soil salinities are about 2 mmh/cm higher than for nongypsiferous soils. Date palm would be affected at 10 mmh/cm, grapes at 6 mmh/cm, etc. on gypsiferous soils.

[b] Estimated.

[c] Lemon is more sensitive than orange and grapefruit; raspberry more than boysenberry and blackberry. Bernstein 1965b[314].

TABLE V-8—Salt Tolerance of Ornamental Shrubs

(Maximum EC_e's tolerated)

Tolerant	Moderately tolerant	Sensitive	Very sensitive
6-10	4-6	2-4	2
Carissa grandiflora (Natal plum)	Dracaena endivisa	Hibiscus rosa-sinensis var. Brilliante	Ilex cornuta Burford (Burford holly)
Bougainvillea spectabilis (Bogainvillea)	Thuja orientalis (arbor vitae)	Nandina domestica (heavenly bamboo)	Hedera canariensis (Algerian ivy)
Nerium oleander (oleander)	Juniperus chinensis (spreading juniper)	Trachelospermum jasminoides (star jasmine)	Feijoa sellowiana (pineapple guava)
Rosmarinus lockwoodi (Rosmary)	Euonymus japonica grandiflora	Viburnum tinus robustum	Rosa sp. (var. Grenoble rose on Dr. Huey root)
Dodonea viscosa atropurpurea	Lantana camara		
	Elaeagnus pungens (silverberry)		
Callistemon viminalis (bottlebrush)	Xylosma senticosa		
	Pittosporum tobira		
	Pyracantha Graberi		
	Ligustrum lucidum (Texas privet)		
	Buxus microphylla japonica (Japanese boxwood)		

Bernstein 1965b[314].

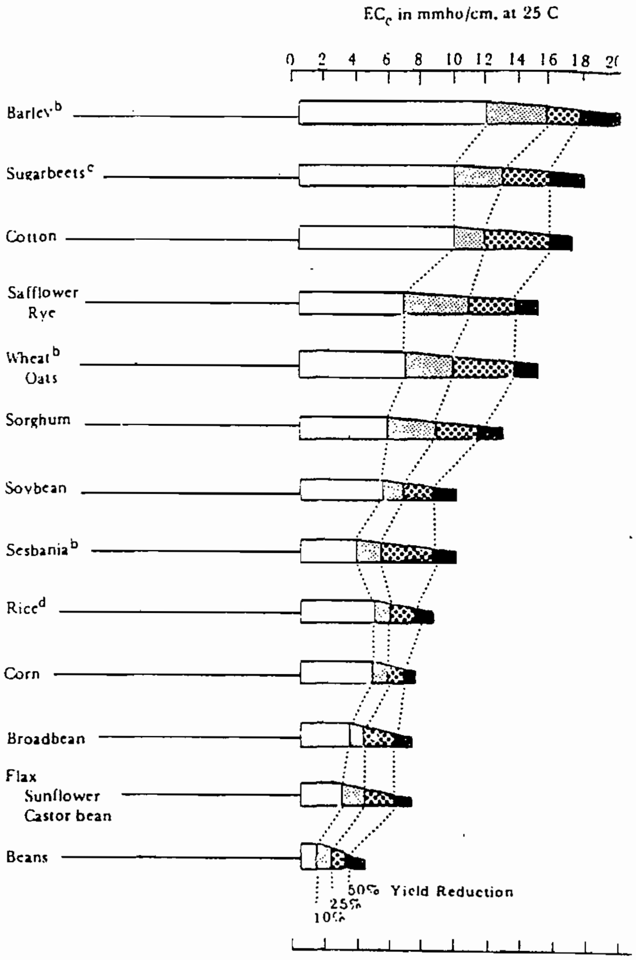


FIGURE V-1—Salt Tolerance of Field Crops[a]

[a] The indicated salt tolerances apply to the period of rapid plant growth and maturation, from the late seeding stage upward. Crops in each category are ranked in order of decreasing salt tolerance. Width of the bar next to each crop indicates the effect of increasing salinity on yield. Crosslines are placed at 10, 25, and 50 per cent yield reductions. Approximate rank in order of decreasing salt tolerance is indicated for additional crops for most of which complete data are lacking. (Bower *personal communication* 1972)238

[b] Less tolerant during seedling stage. Salinity at this stage should not exceed 4 or 5 mmho/cm. EC_e.

[c] Sensitive during germination. Salinity should not exceed 3 mmho/cm during germination.

[d] Less tolerant during flowering and seed-set as well as during the seedling stage. Salinity at sensitive stages should not exceed 4 mmho/cm. EC_e of soil water.

yields of that plant grown on a nonsaline soil under comparable growing conditions. Work has been done by many investigators, based upon both field and greenhouse research, to evaluate salt tolerance of a broad variety of plants. In general, where comparable criteria were used to assess salt tolerance, results obtained were most often in agreement. Recent work on the salt tolerance of fruit crops is shown in Table V-7, and for ornamentals in Table V-8.

Bernstein (1965a[313]) gave EC_e values causing 10, 25, and 50 per cent yield decrements for a variety of field and forage crops from late seeding stage to maturity, assuming that sodium or chloride toxicity was not a growth deterrent. These values are shown in Figures V-1, V-2, and V-3. The data suggested that the effects of EC_e values producing 10 to 50 per cent decrements (within a range of EC_e values of 8 to 10 mmh/cm for many crops) may be considered approximately linear, but for nearly all crops the rate of change

$EC_e \dfrac{\Delta y}{\Delta EC_e}$, either steepens or flattens slightly as the yield

decrements increase from less than 25 to more than 25 per cent. Bernstein (1965a)[313] also pointed out that most fruit crops were more sensitive to salinity than were field, forage, or vegetable crops. The data also illustrated the highly variable effect of EC_e values upon different crops and the nonlinear response of some crops to increasing concentrations of salt.

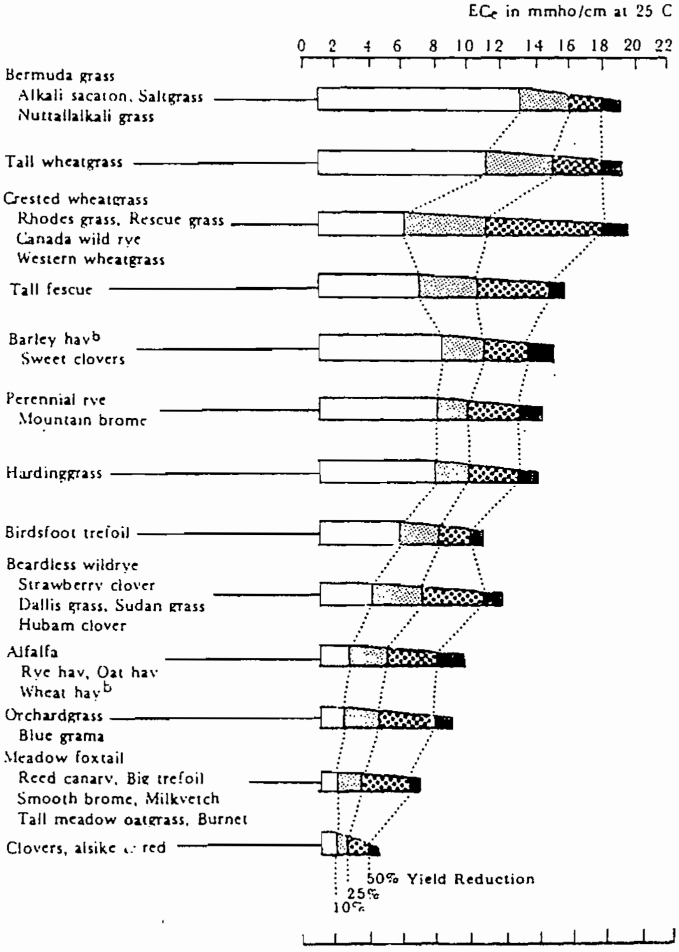
In considering salt tolerances of crops, EC_e values were used. These values were correlated with yields at field moisture content. If soils were allowed to dry out excessively between irrigations, yield reductions were much greater, since the total soil water stress is a function of both matric suction and solute suction and increases exponentially on drying (Bernstein 1965a).[313] Good irrigation managem can minimize this hazard.

Nutritional Effects

Plants require a blanced nutrient content in the solution to maintain optimum growth. Use of saline wa for irrigation may or may not significantly upset this nut tional balance depending upon the composition, concent tion, and volume of irrigation water applied.

Some of the possible nutritional effects were summarized by Bernstein (1965a)[313] as follows:

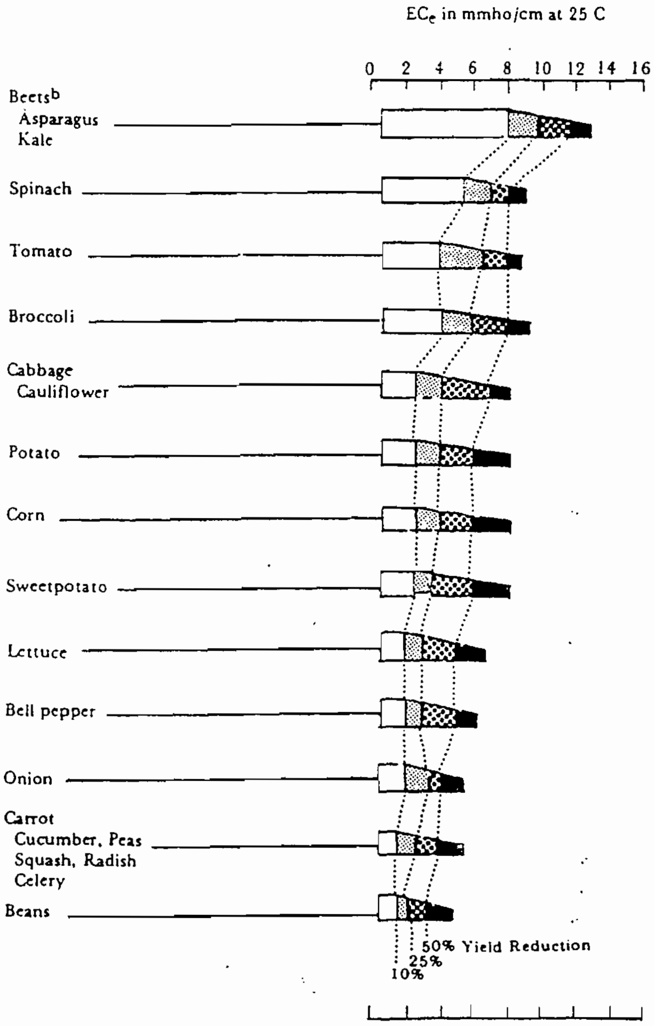
> High concentrations of calcium ions in the solution may prevent the plant from absorbing enough potassium, or high concentrations of other ions may affect the uptake of sufficient calcium.
>
> Different crops vary widely in their requirements for given nutrients and in their ability to absorb them. Nutritional effects of salinity, therefore, appear only in certain crops and only when a particular type of saline condition exists.
>
> Some varieties of a particular crop may be immune to nutritional disturbances, while other varieties are severely affected. High levels of soluble sulfate cause internal browning (a calcium deficiency symptom) in some lettuce varieties, but not in others. Similarly, high levels of calcium cause greater nutritional disturbances in some carrot varieties than in others. Chemical analysis of the plant is useful in diagnosing these effects.



[a] See Figure V-1. (Bower *personal communication* 1972)338

[b] Less tolerant during seedling stage. Salinity at this state should not exceed 4 or 5 mmho/cm. EC_e.

FIGURE V-2—Salt Tolerance of Forage Crops[a]



[a] See Figure V-1. (Bower *personal communication* 1972)338

[b] Sensitive during germination. Salinity should not exceed 3 mmho/cm EC_e during germination.

FIGURE V-3—Salt Tolerance of Vegetable Crops[a]

> At a given level of salinity, growth and yield are depressed more when nutrition is disturbed than when nutrition is normal. Nutritional effects, fortunately, are not important in most crops under saline conditions; when they do occur, the use of better adapted varieties may be advisable.

Recommendation

Crops vary considerably in their tolerance to soil salinity in the root zone, and the factors affecting

the soil solution and crop tolerance are varied and complex. Therefore, no recommendation can be given for these. For specific crops, however, it is recommended that the salt tolerance values (EC_e) for a saturation extract established by the U.S. Salinity Laboratory Staff be used as a guide for production.

Temperature

The temperature of irrigation water has a direct and indirect effect on plant growth. Each occurs when plant physiological functions are impaired by excessively high or excessively low temperatures. The exact water temperatures at which growth is severely restricted depends on method of water application, atmospheric conditions at the time of application, frequency of application, and plant species. All plant species have a tempeature range in which they develop best. These temperature limits vary with plant species.

Direct effect on plant growth from extreme temperature of the irrigation water occurs when the water is first applied. Plant damage results only from direct contact. Normally, few problems arise when excessively warm water is applied by sprinkler irrigation. The effect of the temperature of the water on the temperature of the soil is negligible. It has been demonstrated that warm water applied through a sprinkler system has attained ambient temperatures at the time it reaches the soil surface (Cline et al. 1969).[318] Water as warm as 130 F can be safely used in this manner. Cold water is harmful to plant growth when applied through a sprinkler system. It does not change in temperature nearly so much as the warm water. However, its effect is rarely lethal.

Surface applied water that is either very cold or very warm poses greater problems. Excessive warm water cannot be used for surface irrigation and cold water affects plant growth. The adverse effects of cold water on the growth of rice were suddenly brought to the attention of rice growers when cold water was first released from the Shasta Reservoir in California (Raney 1963).[332] Summer water temperatures were suddenly dropped from about 61 F to 45 F. Research is still proceeding, and some of the available information was recently reviewed by Raney and Mihara (1967).[334] Dams such as the Oroville Dam are now being planned so that water can be withdrawn from any reservoir depth to avoid the cold-water problem. Warming basins have been used (Raney 1959).[333] There are opportunities in planning to separate waters—the warm waters for recreation and agriculture, the cold waters for cold-water fish, salmon spawning, and other uses. The exact nature of the mechanisms by which damage occurs is not completely understood.

Indirect effect of the temperature of irrigation water on plant growth occurs as a result of its influence on the temperature of the soil. The latter affects the rate of water uptake, nutrient uptake, translocation of metabolites indirectly, such factors as stomatal opening and plant stress. All these phenomena are well documented. The of the temperature of the applied irrigation water temperature of the soil is not well described. This ef probably quite small.

Conclusion

Present literature does not provide adequate to establish specific temperature recommenda for irrigation waters. Therefore, no specific rec mendations can be made at this time.

Chlorides

Chlorides in irrigation waters are not generally to crops. Certain fruit crops are, however, sensitive to chlo Bernstein (1967)[312] indicated that maximum permi chloride concentrations in the soil range from 10 t milliequivalents (meq)/l for certain sensitive fruit (Table V-9). In terms of permissible chloride conce tions in irrigation water, values up to 20 meq/l can be depending upon environmental conditions, crops, and ir tion management practices.

Foliar absorption of chlorides can be of importanc sprinkler irrigation (Eaton and Harding 1959,[319] Ehlig Bernstein 1959[320]). The adverse effects vary between ev

TABLE V-9—Salt Tolerance of Fruit Crop Varieties Rootstocks and Tolerable Chloride Levels in the Saturat Extracts

Crop	Rootstock or variety		Tolerable lev chloride in satu extract
	Rootstocks		meq/l
Citrus	Rangpur lime, Cleopatra mandarin		25
	Rough lemon, tangelo, sour orange		15
	Sweet orange, citrange		10
Stone fruit	Marianna		25
	Lovell, Shalil		10
	Yunnan		7
Avocado	West Indian		8
	Mexican		5
	Varieties (V) and Rootstocks (R)		
Grape	Salt Creek, 1613-3	R	40
	Dog Ridge		30
	Thompson Seedless, Perlette	V	20
	Cardinal, Black Rose		10
	Varieties		
Berries	Boysenberry		10
	Olallie blackberry		10
	Indian Summer raspberry		5
Strawberry	Lassen		8
	Shasta		5

Bernstein 1967[312].

rative conditions of day and night and the amount of evaporation that can occur between successive wettings (i.e., time after each pass with a slowly revolving sprinkler). There is less effect with nighttime sprinkling and less effect with fixed sprinklers (applying water at a rapid rate). Concentrations as low as 3 meq/l of chloride in irrigation water have been found harmful when used on citrus, stone fruits, and almonds (Bernstein 1967).[312]

Conclusion

Permissible chloride concentrations depend upon type of crop, environmental conditions and management practices. A single value cannot be given, and no limits should be established, because detrimental effects from salinity per se ordinarily deter crop growth first.

Bicarbonates

High bicarbonate water may induce iron chlorisis by making iron unavailable to plants (Brown and Wadleigh 1955).[317] Problems have been noted with apples and pears (Pratt 1966)[330] and with some ornamentals (Lunt et al. 1956).[323] Although concentrations of 10 to 20 meq/l of bicarbonate can cause chlorosis in some plants, it is of little concern in the field where precipitation of calcium carbonate minimizes this hazard.

Conclusion

Specific recommendations for bicarbonates cannot be given without consideration of other soil and water constituents.

Sodium

The presence of relatively high concentration of sodium in irrigation waters affects irrigated crops in many ways. In addition to its effect on soil structure and permeability, sodium has been found by Lilleland et al. (1945)[322] and Ayers et al. (1952)[311] to be absorbed by plants and cause leaf burn in almonds, avocados, and in stone fruits grown in culture solutions. Bernstein (1967)[312] has indicated that water having SAR* values of four to eight may injure sodium-sensitive plants. It is difficult to separate the specific toxic effects of sodium from the effect of adsorbed sodium on soil structure. (This factor will be discussed later.)

As has been noted, the complex interactions of the total and relative concentrations of these common ions upon various crops preclude their consideration as individual components for general irrigation use, except for sodium and possibly chlorides in areas where fruit would be important.

Nitrate

The presence of nitrate in natural irrigation waters may be considered an asset rather than a liability with respect to plant growth. Concentrations high enough to adversely affect plant growth or composition are seldom, if ever, found. In arid regions, high nitrate water may result in nitrate accumulations in the soil in much the same manner as salt accumulates. The same soil and water management practices that minimize salt accumulation will also minimize nitrate accumulation. There is some concern over the high nitrate content of food and feed crops. Many factors such as plant species characteristics, climate conditions, and growth stage are just as significant in determining nitrate accumulations in plants as the amount present in the soil. It is unlikely that any nitrate added in natural irrigation water could be a significant factor.

Problems may arise where waste waters containing relatively large amounts of nitrogenous materials are used for irrigation. Larger amounts are usually applied than that actually required for plant growth. These wastes, however, usually contain nitrogen in a form that is slowly converted to nitrate. Nevertheless, it is possible that high nitrate accumulations in plants may occur although little evidence is available to indicate this.

Conclusion

Since nitrate in natural irrigation waters is usually an asset for plant growth and there is little evidence indicating that it will accumulate to toxic levels in irrigated plants consumed by animals, there appears to be no need for a recommendation.

Effects on Soils

Sodium Hazard Sodium in irrigation water may become a problem in the soil solution as a component of total salinity, which can increase the osmotic concentration, and as a specific source of injury to fruits. The problems of sodium mainly occur in soil structure, infiltration, and permeability rates. Since good drainage is essential for management of salinity in irrigation and for reclamation of saline lands, good soil structure and permeability must be maintained. A high percentage of exchangeable sodium in a soil containing swelling-type clays results in a dispersed condition, which is unfavorable for water movement and plant growth. Anything that alters the composition of the soil solution, such as irrigation or fertilization, disturbs the equilibrium and alters the distribution of adsorbed ions in the soil. When calcium is the predominant cation adsorbed on the soil exchange complex, the soil tends to have a granular structure that is easily worked and readily permeable. When the amount of adsorbed sodium exceeds 10 to 15 per cent of the total cations on the exchange complex, the clay becomes dispersed and slowly permeable, unless a high concentration of total salts causes flocculation. Where soils have a high exchangeable sodium content and are flocculated because of the presence of free salts in solution, subsequent removal of salts by leaching will cause sodium

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* For definition of SAR, Sodium Adsorption Ratio, see p. 330.

dispersal, unless leaching is accomplished by adding calcium or calcium-producing amendments.

Adsorption of sodium from a given irrigation water is a function of the proportion of sodium to divalent cations (calcium and magnesium) in that water. To estimate the degree to which sodium will be adsorbed by a soil from a given water when brought into equilibrium with it, the Salinity Laboratory (1954)[335] proposed the sodium adsorption ratio (SAR):

$$\frac{Na^+}{\sqrt{\frac{Ca^{++}+Mg^{++}}{2}}} \qquad \text{Expressed as me/l}$$

As soils tend to dry, the SAR value of the soil solution increases even though the relative concentrations of the cations remain the same. This is apparent from the SAR equation, where the denominator is a square-root function. This is a significant factor in estimating sodium effects on soils.

The SAR value can be related to the amount of exchangeable cation content. This latter value is called the exchangeable sodium percentage (ESP). From empirical determinations, the U. S. Salinity Laboratory (1954)[335] obtained an equation for predicting a soil ESP value based on the SAR value of a water in equilibrium with it. This is expressed as follows:

$$ESP = \frac{[100\ a + b(SAR)]}{[1 + a + b(SAR)]}$$

The constants "a" (intercept representing experimental error) and "b" (slope of the regression line) were determined statistically by various investigators who found "a" to be in the order of −0.06 to 0.01 and "b" to be within the range of 0.014 to 0.016. This relationship is shown in the nomogram (Figure V-4) developed by the U. S. Salinity Laboratory (1954).[335] For sensitive fruits, the tolerance limit for SAR of irrigation water is about four. For general crops, a limit of eight to 18 is generally considered within a usable range, although this depends to some degree on the type of clay mineral, electrolyte concentration in the water, and other variables.

The ESP value that significantly affects soil properties varies according to the proportion of swelling and nonswelling clay minerals. An ESP of 10 to 15 per cent is considered excessive, if a high percentage of swelling clay minerals such as montmorillonite are present. Fair crop growth of alfalfa, cotton, and even olives, have been observed in soils of the San Joaquin Valley (California) with ESP values ranging from 60 to 70 percent (Schoonover 1963).[336]

Prediction of the equilibrium ESP from SAR values of irrigation waters is complicated by the fact that the salt content of irrigation water becomes more concentrated in the soil solution. According to the U. S. Salinity Laboratory (1954),[335] shallow ground waters 10 times as saline as irrigation waters may be found within depths of 10 feet, a salt concentration two to three times that of irrigat water may be reasonably expected in the first-foot dep Under conditions where precipitation of salts and rain may be neglected, the salt content of irrigation water increase to higher concentrations in the soil solution with change in relative composition. The SAR increases proportion to the square root of the concentration; the fore, the SAR applicable for calculating equilibrium E in the upper root zone may be assumed to be two to th times that of the irrigation water.

Recommendation

To reduce the sodium hazard in irrigation wat for a specific crop, it is recommended that the SA value be within the tolerance limits determined the U.S. Soil Salinity Laboratory Staff.

Biochemical Oxygen Demand (BOD) and Soil Aeration

The need for adequate oxygen in the soil for optimu plant growth is well recognized. To meet the oxygen r quirement of the plant, soil structure (porosity) and s water contents must be adequate to permit good aeratio. Conditions that develop immediately following irrigatio are not clearly understood.

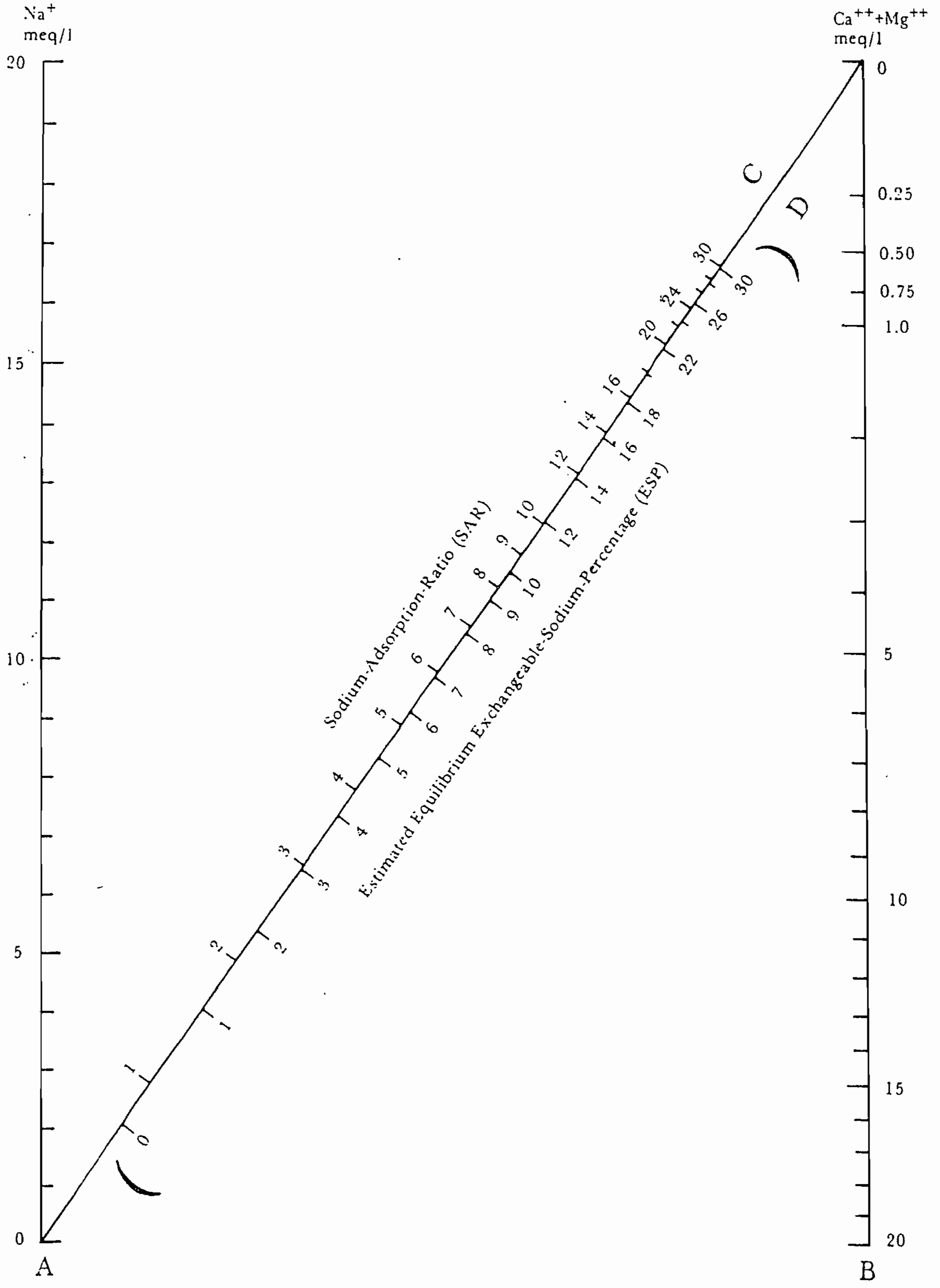
Soil aeration and oxygen availability normally present n problem on well-structured soils with good quality wate Where drainage is poor, oxygen may become limitin Utilization of waters having high BOD or Chemical Oxyge Demand (COD) values could aggravate the condition b further depleting available oxygen. Aside from detrimenta effects of oxygen deficiency for plant growth, reduction elements such as iron and manganese to the more solubl divalent forms may create toxic conditions. Other biologica and chemical equilibria may also be affected.

There is very little information regarding the effect c using irrigation waters with high BOD values on plan growth. Between source of contamination and point of irrigation, considerable reduction in BOD value may result Sprinkler irrigation may further reduce the BOD value o water. Infiltration into well-drained soils can also decreas the BOD value of the water without serious depleting th oxygen available for plant growth.

Acidity and Alkalinity

The pH of normal irrigation water has little direct significance. Since water itself is unbuffered, and the soil is a buffered system (except for extremely sandy soils low in organic matter), the pH of the soil will not be significantly affected by application of irrigation water. There are, however, some extremes and indirect effects.

Water having pH values below 4.8 applied to acid soils over a period of time may possibly render soluble iron,



Salinity Laboratory 1954 335

FIGURE V-4—Nomogram for Determining the SAR Value of Irrigation Water and for Estimating the Corresponding ESP Value of a Soil That is at Equilibrium with the Water aluminum, or manganese in concentrations large enough to be toxic to plant growth. Similarly, additions of saline waters to acid soils could result in a decrease in soil pH and an increase in the solubility of aluminum and manganese. In some areas where acid mine drainage contaminates water sources, pH values as low as 1.8 have been reported. Waters having unusually low pH values such as this would be strongly suspect of containing toxic quantities of certain heavy metals or other elements.

Waters having pH values in excess of 8.3 are highly alkaline and may contain high concentrations of sodium, carbonates, and bicarbonates. These constituents affect soils and plant growth directly or indirectly, (see "Effects on Plant Growth" above).

Recommendation

Because most of the effects of acidity and alkalinity in irrigation waters on soils and plant growth are indirect, no specific pH values can be recommended. However, water with pH values in the range of 4.5 to 9.0 should be usable provided that care is taken to detect the development of harmful indirect effects.

Suspended Solids

Deposition of colloidal particles on the soil surface can produce crusts that inhibit water infiltration and seedling emergence. This same deposition and crusting can reduce soil aeration and impede plant development. High colloidal content in water used for sprinkler irrigation could result in deposition of films on leaf surfaces that could reduce photosynthetic activity and thereby deter growth. Where sprinkler irrigation is used for leafy vegetable crops such as lettuce, sediment may accumulate on the growing plant affecting the marketability of these products.

In surface irrigation, suspended solids can interfere with the flow of water in conveyance systems and structures. Deposition of sediment not only reduces the capacity of these systems to carry and distribute water but can also decrease reservoir storage capacity. For sprinkler irrigation, suspended mineral solids may cause undue wear on irrigation pumps and sprinkler nozzles (as well as plugging up the latter), thereby reducing irrigation efficiency.

Soils are specifically affected by deposition of these suspended solids, especially when they consist primarily of clays or colloidal material. These cause crust formations that reduce seedling emergence. In addition, these crusts reduce infiltration and hinder the leaching of saline soils. The scouring action of sediment in streams has also been found to affect soils adversely by contributing to the dissolution and increase of salts in some areas (Pillsbury and Blaney 1966).[331] Conversely, sediment high in silt may improve the texture, consistency, and water-holding capacity of a sandy soil.

Effect on Animals or Humans

The effects of irrigation water quality on soils and pl
has been discussed. However, since the quality of irriga
water is variable and originates from different sources, t
may be natural or added substances in the water which
a hazard to animals or humans consuming irrigated cr
These substances may be accumulated in certain cer
pasture plants, or fruit and vegetable crops without
apparent injury. Of concern, however, is that the con
tration of these substances may be toxic or harmful
humans or animals consuming the plants. Many substa
in irrigation waters such as inorganic salts and miner
pesticides, human and animal pathogens have recommen
tions to protect the desired resource. For radionuclides
such recommendation exists.

Radionuclides

There are no generally accepted standards for contro
radioactive contamination in irrigation water. For n
radionuclides, the use of federal Drinking Water Standa
should be reasonable for irrigation water.

The limiting factor for radioactive contamination in
rigation is its transfer to foods and eventual intake
humans. Such a level of contamination would be reac
long before any damage to plants themselves could be
served. Plants can absorb radionuclides from irrigat
water in two ways: direct contamination of foliage thro
sprinkler irrigation, and indirectly through soil contami
tion. The latter presents many complex problems si
eventual concentration in the soil will depend on the r
of water application, the rate of radioactive decay, a
other losses of the radionuclide from the soil. Some stud
relating to these factors have been reported (Menzel et
1963,[326] Moorby and Squire 1963,[328] Perrin 1963,[329] Men
1965,[325] Milbourn and Taylor 1965[327]).

It is estimated that concentrations of strontium-90 a
radium-226 in fresh produce would approximate those
the irrigation water for the crop if there was negligible
take of these radionuclides from the soil. With flood or f
row irrigation only, one or more decades of continuous
rigation with contaminated water would be required bef
the concentrations of strontium-90 or radium-226 in
produce equalled those in the water (Menzel *personal co
munication* 1972).[339]

Recommendation

**In view of the lack of experimental evidence co
cerning the long-term accumulation and avai
ability of strontium-90 and radium-226 in irrigate
soils and to provide an adequate margin of safet
it is recommended that Federal Drinking Wat
Standards be used for irrigation water.**

SPECIFIC IRRIGATION WATER CONSIDERATIONS

Irrigation Water Quality for Arid and Semiarid Regions

Climate. Climatic variability exists in arid and semiarid regions. There can be heavy winter precipitation, generally increasing from south to north and increasing with elevation. Summer showers are common, increasing north and east from California. Common through the western part of the country is the inadequacy of precipitation during the growing season. In most areas of the West, intensive agriculture is not possible without irrigation. Irrigation must supply at least one-half of all the soil water required annually for crops for periods ranging from three to 12 months.

Annual precipitation varies in the western United States from practically zero in the southwestern deserts to more than 100 inches in the upper western slope of the Pacific Northwest. The distribution of precipitation throughout the year also varies, with no rainfall during extended periods in many locales. Often the rainfall occurs during nongrowing seasons.

The amount of precipitation and its distribution is one of the principal variables in determining the diversion requirement or demand for irrigation water.

Land. Soils in the semiarid and arid regions were developed under dry climatic conditions with little leaching of weatherable minerals in the surface horizon. Consequently, these soils are better supplied with most nutrient elements. The pH of these soils varies from being slightly acidic to neutral or alkaline. The presence of silicate clay minerals of the montmorillonite and hydrous mica groups in many of these soils gives them a higher exchange capacity than those of the southeast, which contain kaolinite minerals of lower exchange capacity. However, organic matter and nitrogen contents of arid soil are usually lower. Plant deficiencies of trace elements such as zinc, iron, manganese are more frequently encountered. Because of the less frequent passage of water through arid soils, they are more apt to be saline.

The nature of the surface horizon (plow layer) and the subsoil is especially important for irrigation. During soil formation a profile can develop consisting of various horizons. The horizons consist of genetically related layers of soil or soil material parallel to the land surface, and they differ in their chemical, physical, and biological properties. The productivity of a soil is largely determined by the nature of these horizons. Soils available for irrigation with restrictive or impervious horizons present management problems (e.g., drainage, aeration, salt accumulation in root zone, changes in soil structure) and consequently are not the best for irrigated agriculture.

Other land and soil factors of importance to irrigation are topography and slope, which may influence the choice of irrigation method, and soil characteristics. The latter are extremely important because they determine the usable depth of water that can be stored in the root zone of the crop and the erodability and intake rate of the soil.

Water. Each river system within the arid and semiarid portion of the United States has quality characteristics peculiar to its geologic origin and climatic environment. In considering water quality characteristics as related to irrigation, both historic and current data for the stream and location in question should be used with care because of the large seasonal and sporadic variations that occur.

The range of sediment concentrations of a river throughout the year is usually much greater than the range of dissolved solids concentrations. Maximum sediment concentrations may range from 10 to more than a thousand times the minimum concentrations. Usually, the sediment concentrations are higher during high flow than during low flow. This differs inversely from dissolved-solids concentrations that are usually lower during high flows.

Four general designations of water have been used (Rainwater 1962)[361] based on their chemical composition: (1) calcium-magnesium, carbonate-bicarbonate; (2) calcium-magnesium, sulfate-chloride; (2) sodium-potassium, carbonate-bicarbonate; and (4) sodium-potassium, sulfate-chloride. This type of classification characterizes the chemical properties of the water and would be indicative of reactions that could be expected with soil when used for irrigation. Although a listing of data for each stream and tributary is beyond the scope of this report, an indication of ranges in dissolved-solids concentrations, chemical type, and sediment concentration is given in Table V-10 (Rainwater 1962).[361]

Customarily, each irrigation project diverts water at one point in the river and the return flow comes back into the mainstream somewhere below the system. This return flow consists in the main of (1) regulatory water, which is the unused part of the diverted water required so that each farmer irrigating can have the exact flow he has ordered;

TABLE V-10—Variations in Dissolved Solids, Chemical Type, and Sediment in Rivers in Arid and Semiarid United States

Region	Dissolved solids concentrations, mg/l From	To	Prevalent chemical type[a]	Sediment concentrations, mg/l[b] From	To
Columbia River Basin	<100	300	Ca-Mg, C-b	<200	300
Northern California	<100	700	Ca-Mg, C-b	<200	+500
Southern California	<100	+2,000	Ca-Mg, C-b; Ca-Mg, S-C	<200	+15.000
Colorado River Basin	<100	+2.500	Ca-Mg, S-C; Ca-Mg, C-b	<200	+15,000
Rio Grande Basin	<100	+2,000	Ca-Mg, C-b; Ca-Mg, S-C	+300	+50,000
Pecos River Basin	100	+3,000	Ca-Mg, S-C	+300	+7,000
Western Gulf of Mexico Basins	100	+3.000	Ca-Mg, C-b; Ca-Mg, S-C; Na-P, S-C	<200	+30,000
Red River Basin	<100	+2.500	Ca-Mg, S-C; Na-P, S-C	+300	+25,000
Arkansas River Basin	100	+2.000	Ca-Mg, S-C; Ca-Mg, C-b; Na-P, S-C	+300	+30,000
Platte River	100	+1.500	Ca-Mg, C-b; Ca-Mg, S-C	+300	+7,000
Upper Missouri River Basin	100	+2,000	Ca-Mg, S-C; Na-P, C-b; Na-P, C-b	<200	+15,000

[a] Ca-Mg, C-b = Calcium-magnesium, carbonate-bicarbonate. Ca-Mg, S-C = Calcium-magnesium, sulfate-chloride. Na-P, C-b = Sodium-potassium, carbonate-bicarbonate. Na-P, S-C = Sodium-potassium, sulfate-chloride.

[b] $\text{Sediment concentration} = \frac{\text{Annual Load}}{\text{Annual Streamflow}}$

Rainwater 1962[361].

(2) tail water, which is that portion of the water that runs off the ends of the fields: and (3) underground drainage, required to provide adequate application and salt balance in all parts of the fields. The initial flush of tail water may be somewhat more saline than later but rapidly approaches the same quality as the applied water (Reeve et al. 1955).[362]

Drainage and Leaching Requirements. In all irrigation agriculture some water must pass through the soil to remove salts brought to the soil in the water. In semiarid areas, or in the transition zone between arid and humid regions, this drainage water is usually obtained as a result of rainfall during periods of low evapotranspiration, and no excess irrigation water is needed to provide the drainage required. In many arid regions, the needed leaching must be obtained by adding excess water. In all cases, the required drainage volume is related to the amount of salt in the irrigation water. That drainage volume is called the leaching requirement (LR).

It is possible to predict the approximate salt concentration that would occur in the soil after a number of irrigations by estimating the proportion of applied water that will percolate below the root zone. In any steady-state leaching formula, the following assumptions are made:

- No precipitation of salts occurs in the soil;
- Ion uptake by plants is negligible;
- There is uniform distribution of soil moisture through the profile and uniform concentration of salts in the soil moisture;
- Complete and uniform mixing of irrigation water with soil moisture takes place before any of the moisture percolates below the root zone and
- Residual soil moisture is negligible.

A steady state leaching requirement formula has been developed by the U.S. Salinity Laboratory (1954)[363] designed to estimate that fraction of the irrigation water that must be leached through the root zone to control soil salinity at any specified level. This is given as:

$$LR = \frac{D_{dw}}{D_{iw}} = \frac{EC_{iw}}{EC_{dw}}$$

where LR is the leaching requirement; D_{dw}, the depth of drainage water; D_{iw}, the depth of irrigation water; EC_{iw}, the salinity of irrigation water; and EC_{dw}, the salinity of water percolating past root zone.

Hence, if EC_{dw} is determined by the salt tolerance of the crop to be grown, and the salt content of the irrigation water EC_{iw} is known, the desired LR can be calculated. This leaching fraction will then be the ratio of depth of drainage volume to the depth of irrigation water applied.

Because the permissible values for EC_{dw} for various yield decrements for various crops are not known, the EC_e for 50 per cent yield reduction has been substituted for EC_{dw}. The actual yield reduction will probably be less than 50 per cent (Bernstein 1966).[340] This EC_e is the assumed average electrical conductivity for the soil water at saturation the whole root zone. When it is substituted for the E the actual EC_e encountered in the root zone will be than this value because, in many near steady state si tions, the salinity increases progressively with increas depth in the profile and is maximum at the bottom of root zone.

Bernstein (1967)[341] has developed a leaching frac formula that takes into consideration factors that con leaching rates such as infiltration rate, climate (evapotr piration), frequency and duration of irrigation, and course, the salt tolerance of the crops. He defines leaching fraction as $LF = 1 - ET_e/IT_1$ where LF is the lea ing fraction or proportion of applied water percola below the root zone; E, the average rate of evapotransp tion during the irrigation cycle, T_e; and I, the average filtration rate during the period of infiltration, T_1. By ut ing both the required leaching derived from the steady s formula

$$LR = \frac{EC_{iw}}{EC_{dw}}$$

and the leaching fraction based upon infiltration rates evapotranspiration during the irrigation cycle, it is poss to estimate whether adequate leaching can be attained whether adjustments must be made in the crops to grown to permit higher salinity concentrations.

In addition to determination of crops to be gro leaching requirements may be used to indicate the t quantities of water required. For example, irrigation wa with a conductivity of two mmhos requires one-sixth m water to maintain root zone salt concentrations wit eight mmhos than would water with a salt concentration one mmhos under the same conditions of use.

There are a number of problems in applying the leach requirement concept in actual practice. Some of these rel to the basic assumptions involved and others derive fr water application problems and soil variability.

- Considerable precipitation of calcium carbonate curs as many irrigation waters enter the soil causin reduction in the total soluble salt load. In ma crops, or crop rotations, crop removal of such i as chloride was a significant fraction of the to added in waters of medium to low salinity. (Pr et al. 1967)[359]
- It is not practical to apply water with complete u formity.
- Soils are far from uniform, particularly with resp to vertical hydraulic conductivity.
- The effluent from tile or ditch drains may not representative of the salinity of water at the botto of the root zones.

Also, there is a considerable variation in drainage outflo that has no relation to leaching requirement when differe crops are irrigated (Pillsbury and Johnston 1965).[357] This results from variations in irrigation practices for the different crops.

The leaching requirement concept, while very useful, should not be used as a sole guide in the field. The leaching requirement is a long-period average value that can be departed from for short periods with adequately drained soils to make temporary use of water poorer in quality than customarily applied.

The exact manner in which leaching occurs and the appropriate values to be used in leaching requirement formulas require further study. The many variables and assumptions involved preclude a precise determination under field conditions.

Salinity Hazard. Waters with total dissolved solids (TDS) less than about 500 mg/l are usually used by farmers without awareness of any salinity problem, unless, of course, there is a high water table. Also, without dilution from precipitation or an alternative supply, waters with TDS of about 5,000 mg/l usually have little value for irrigation (Pillsbury and Blaney 1966).[356] Within these limits, the *value* of the water appears to decrease as the salinity increases. Where water is to be used regularly for the irrigation of relatively impervious soil, its value is limited if the TDS is in the range of 2,000 mg/l or higher.

Recommendation

In spite of the facts that (1) any TDS limits used in classifying the salinity hazard of waters are somewhat arbitrary; (2) the hazard is related not only to the TDS but also to the individual ions involved; and (3) no exact hazard can be assessed unless the soil, crop, and acceptable yield reductions are known, Table V-11 suggests classifications for general purposes for arid and semiarid regions.

TABLE V-11—Recommended Guidelines for Salinity in Irrigation Water

Classification	TDS mg/l	EC mmhos/cm
Water for which no detrimental effects are usually noticed..........	500	0.75
Water that can have detrimental effects on sensitive crops..........	500–1,000	0.75–1.50
Water that can have adverse effects on many crops; requires careful management practices	1,000–2,000	1.50–3.00
Water that can be used for tolerant plants on permeable soils with careful management practices	2,000–5,000	3.00–7.50

Permeability Hazard. Two criteria used to evaluate the effect of salts in irrigation water on soil permeability are: (1) the sodium adsorption ratio (SAR) and its relation to the exchangeable sodium percentage, and (2) the bicarbonate hazard that is particularly applicable to waters of arid regions. Another factor related to the permeability hazard is that the permeability tends to increase, and the stability of a soil at any exchangeable sodium percentage (ESP) increases as the salinity of the water increases (Quirk and Schofield 1955).[360]

Eaton (1950),[347] Doneen (1959),[346] and Christiansen and Thorne (1966)[345] have recognized that the permeability hazard of irrigation waters containing bicarbonate was greater than indicated by their SAR values. Bower and Wilcox (1965)[343] found that the tendency for calcium carbonate to precipitate in soils was related to the Langelier index (Langelier 1936)[349] and to the fraction of the irrigation water evapotranspired from the soil. Bower et al. (1965,[344] 1968)[342] modified the Langelier index or precipitation index (PI) to the soil system and presented simplified means for calculation. The PI was 8.4-pH_c, where 8.4 was the pH of the soil and pH_c, the pH that would be found in a calcium carbonate suspension that would have the same calcium and bicarbonate concentrations as those in the irrigation water. For the soil system

$$pH_c = pK_2 - pK_c + p(Ca+Mg) + pAlk$$

where pK_2 and pK_c are the negative logarithms, respectively, of the second dissociation constant for carbonic acid and the solubility constant for calcite: p(Ca+Mg) and pAlk are the negative logarithms, respectively, of the molar concentrations of (Ca+Mg) and the titrable alkalinity. Magnesium is included primarily because it reacts, through cation exchange, to maintain the calcium concentration in solution. The PI combines empirically with the SAR in the following equation

$$SAR_{se} = SAR_{iw}\sqrt{C}(1+PI)$$

where SAR_{se} and SAR_{iw} are for the saturation extract and the irrigation water, respectively, C is the concentration factor or the reciprocal of the leaching fraction, and PI is 8.4-pH_c. Bower et al. (1968)[342] and Pratt and Bair (1969),[358] using lysimeter experiments, have shown a high correlation between the predicted and measured SAR_{se} with waters of various bicarbonate concentrations. The information available suggested a high utility of this equation for calculating permeability or sodium hazard of waters. In cases where C is not known, a value of 4, corresponding to a leaching fraction of 0.25, can be used to give relative comparisons among waters. In this case the equation is

$$SAR_{se} = 2SAR_{iw}(1+PI).$$

Data can be used to prepare graphs, from which the values for $pK_2 - pK_c$, p(Ca+Mg), and pAlk can be obtained for easy calculation of pH_c. The calculation of pH_c is described by Bower et al. (1965).[344]

Soils have individual responses in reduction in permeability as the SAR or calculated SAR values increase, but adverse effects usually begin to appear as the SAR value passes through the range from 8 to 18. Above an SAR of 18 the effects are usually adverse.

Suspended Solids. Suspended organic solids in surface water supplies seldom give trouble in ditch distribution systems except for occasional clogging of gates. They can also carry weed seeds onto fields where their subsequent growth can have a severely adverse effect on the crop or can have a beneficial effect by reducing seepage losses. Where surface water supplies are distributed through pipelines, it is often necessary to have self-cleaning screens to prevent clogging of the pipe system appliances. Finer screening is usually required where water enters pressure-pipe systems for sprinkler irrigation.

There are waters diverted for irrigation that carry heavy inorganic sediment loads. The effects that these loads might have depend in part on the particle size and distribution of the suspended material. For example, the ability of sandy soils to store moisture is greatly improved after the soils are irrigated with muddy water for a period of years. More commonly, sediment tends to fill canals and ditches, causing serious cleaning and dredging problems. It also tends to further reduce the already low infiltration characteristics of slowly permeable soils.

Irrigation Water Quality For Humid Regions

Climate The most striking feature of the climate of the humid region that contrasts with that of the far West and intermountain areas is the larger amount of and less seasonable distribution of the precipitation. Abundant rainfall, rather than lack of it, is the normal expectation. Yet, droughts are common enough to require that attention be given to supplemental irrigation. These times of shortage of water for optimum plant growth can occur at irregular intervals and at almost any stage of plant growth.

Water demands per week or day are not as high in humid as in arid lands. But rainfall is not easily predicted. Thus a crop may be irrigated and immediately thereafter receive a rain of one or two inches. Supplying the proper amount of supplemental irrigation water at the right time is not easy even with adequate equipment and a good water supply. There can be periods of several successive years when supplemental irrigation is not required for most crops in the humid areas. There are times however, when supplemental water can increase yield or avert a crop failure. Supplemental irrigation for high-value crops will undoubtedly increase in humid areas in spite of the fact that much capital is tied up in irrigation equipment during years in which little or no use is made of it.

The range of temperatures in the humid region in which supplemental irrigation is needed is almost as great as that for arid and semiarid areas. It ranges from that of the short growing season of upstate New York and Michigan to the continuous growing season of southern Florida. But in the whole of this area, the most unpredictable factor in crop production is the need for additional water for optimum crop production.

Soils The soils of the humid region contrast with those of the West primarily in being lower in available nutrients. They are generally more acid and may have problems exchangeable aluminum. The texture of soils is simil that found in the West and ranges from sands to clays. S are too permeable, while others take water very slowl

Soils of the humid region generally have clay minera lower exchange capacity than soils of the arid and sem regions and hence lower buffer capacity. They are easily saturated with anions and cations. This is an portant consideration if irrigation with brackish wat necessary to supplement natural rainfall. Organic m content ranges from practically none on some of the Fl sands to 50 per cent or more in irrigated peats.

One of the most important characteristics of many o soils of the humid Southeast is the unfavorable root envi ment of the deeper horizons containing exchange aluminum and having a strong acid reaction. In fact, lack of root penetration of these horizons by most farm c is the primary reason for the need for supplemental ir tion during short droughts.

Specific Difference Between Humid and Regions The effect of a specific water quality dete on plant growth is governed by related factors. principles involved are almost universally applicable, the ultimate effect must take into consideration thes sociated variables. Water quality criteria for suppleme irrigation in humid areas may differ from those indic for arid and semiarid areas where the water requirem of the growing plant are met almost entirely by irrigat

When irrigation water containing a deterrent is use effect on plant growth may vary, however, with the s of growth at which the water is applied. In arid areas, pl may be subjected to the influence of irrigation water qu continuously from germination to harvest. Where wat used for supplemental irrigation only, the effect on pl depends not only upon the growth stage at which app but to the length of time that the deterrent remains in root zone (Lunin et al. 1963).[352] Leaching effects of ir vening rainfall must be taken into consideration.

Climatic differences between humid and arid regions influence criteria for use of irrigation water. The amour rainfall determines in part the degree to which a g constituent will accumulate in the soil. Other factors sociated with salt accumulation in the soil are those clim conditions relating to evapotranspiration. In humid ar evapotranspiration is generally less than in arid regi and plants are not as readily subjected to water stress. importance of climatic conditions in relation to salinity demonstrated by Magistad et al. (1943).[355] In gene criteria regarding salinity for supplemental irrigation humid areas can be more flexible than for arid areas.

Soil characteristics represent another significant differe between arid and humid regions. These were discus previously.

Mineralogical composition will also vary. The comp tion of soil water available for absorption by plant r represents the results of an interaction between the constituents of the irrigation water and the soil complex. The final result may be that a given quality deterrent present in the water could be rendered harmless by the soil (remaining readily available), or that the dissolved constituents of a water may render soluble toxic concentrations of an element that was not present in the irrigation water. An example of this would be the addition of a saline water to an acid soil resulting in a decrease in pH and a possible increase in solubility of elements such as iron, aluminum, and manganese (Eriksson 1952).[348]

General relationships previously derived for SAR and adsorbed sodium in neutral or alkaline soils of arid areas do not apply equally well to acid soils found in humid regions (Lunin and Batchelder 1960).[350] Furthermore, the effect of a given level of adsorbed sodium (ESP) on plant growth is determined to some degree by the associated adsorbed cations. The amount of adsorbed calcium and magnesium relative to adsorbed sodium is of considerable consequence, especially when comparing acidic soils to ones that are neutral or alkaline. Another example would be the presence of a trace element in the irrigation water that might be rendered insoluble when applied to a neutral or alkaline soil, but retained in a soluble, available form in acid soils. For these reasons, soil characteristics, which differ greatly between arid and humid areas, must be taken into consideration.

Certain economic factors also influence water quality criteria for supplemental irrigation. Although the ultimate objective of irrigation is to insure efficient and economic crop production, there may be instances where an adequate supply of good quality water is unavailable to achieve this. A farmer may be faced with the need to use irrigation water of inferior quality to get some economic return and prevent a complete crop failure. This can occur in humid areas during periods of prolonged drought. Water quality criteria are generally designed for optimum production, but consideration must be given also to supplying guidelines for use of water of inferior quality to avert a crop failure.

Specific Quality Criteria for Supplemental Irrigation A previous discussion (see "Water Quality Considerations for Irrigation" above) of potential quality deterrents contained a long list of factors indicating the current state of our knowledge as to how they might relate to plant growth. Criteria can be established by determining a concentration of a given deterrent, which, when adsorbed on or absorbed by a leaf during sprinkler irrigation, results in adverse plant growth, and by evaluating the direct or indirect effects (or both) that a given concentration of a quality deterrent has on the plant root environment as irrigation water enters the soil. Neither evaluation is simple, but the latter is more complex because so many variables are involved. Since sprinkler application in humid areas is most common for supplemental irrigation, both types of evaluation have considerable significance. The following discussion relates only to those quality criteria that are specifically applicable to supplemental irrigation.

Salinity. General concepts regarding soil salinity as previously discussed are applicable. Actual levels of salinity that can be tolerated for supplemental irrigation must take into consideration the leaching effect of rainfall and the fact that soils are usually nonsaline at spring planting. The amount of irrigation water having a given level of salinity that can be applied to the crop will depend upon the number of irrigations between leaching rains, the salt tolerance of the crop, and the salt content of the soil prior to irrigation.

Since it is not realistic to set a single salinity value or even a range that would take these variables into consideration, a guide was developed to aid farmers in safely using saline or brackish waters (Lunin and Gallatin 1960).[351] The following equation was used as a basis for this guide:

$$EC_{e(f)} = EC_{e(i)} + \frac{n(EC_{iw})}{2}$$

where $EC_{e(f)}$ is the electrical conductivity of the saturation extract after irrigation is completed: $EC_{e(i)}$, the electrical conductivity of the soil saturation extract before irrigation: EC_{iw}, the electrical conductivity of the irrigation water; and n, the number of irrigations.

To utilize this guide, the salt tolerance of the crop to be grown and the soil salinity level ($EC_{e(f)}$) that will result in a 15 or 50 per cent yield decrement for that crop must be considered. After evaluating the level of soil salinity prior to irrigation ($EC_{e(i)}$) and the salinity of the irrigation water, the maximum number of permissible irrigations can be calculated. These numbers are based on the assumption that no intervening rainfall occurs in quantities large enough to leach salts from the root zone. Should leaching rainfall occur, the situation could be reevaluated using a new value for $EC_{e(i)}$.

Categorizing the salt tolerance of crops as highly salt tolerant, moderately salt tolerant, and slightly salt tolerant, the guide shown in Table V-12 was prepared to indicate

TABLE V-12—Permissible Number of Irrigations in Humid Areas with Saline Water between Leaching Rains for Crops of Different Salt Tolerance[a]

Irrigation water		Number of irrigations for crops having		
Total salts mg/l	Electrical conductivity mmhos/cm at 25 C	Low salt tolerance	Moderate salt tolerance	High salt tolerance
640	1	7	15	....
1,280	2	4	7	11
1,920	3	2	4–5	7
2,560	4	2	3	5
3,200	5	1	2–3	4
3,840	6	1	2	3
4,480	7	....	1–2	2–3
5,120	8	....	1	2

[a] Based on a 50 per cent yield decrement.

Lunin et al. 1960[354].

the number of permissible irrigations using water of varying salt concentrations. This guide is based on two assumptions:

- no leaching rainfall occurs between irrigations.
- there is no salt accumulation in the soil at the start of the irrigation period. If leaching rains occur between irrigations, the effect of the added salt is minimized. If there is an accumulation of salt in the soil initially, such as might occur when irrigating a fall crop on land to which saline water had been applied during a spring crop, the soil should be tested for salt content, and the irrigation recommendations modified accordingly.

Recommendation

Since it is not realistic to set a single salinity value or even a range that would take all variables into consideration, Table V-12 developed by Lunin et al. (1960),[354] should be used as a guide to aid farmers in safely using saline or brackish waters for supplemental irrigation in humid areas.

SAR values and exchangeable sodium. The principles relating to SAR values and the degree to which sodium is adsorbed from water by soils are generally applicable in both arid and humid regions. Some evidence is available (Lunin and Batchelder 1960),[350] however, to indicate that, for a given water quality, less sodium was adsorbed by an acid soil than by a base-saturated soil. For a given level of exchangeable sodium, preliminary evidence indicated more detrimental effects on acid soils than on base-saturated soils (Lunin et al. 1964).[353]

Experimental evidence is not conclusive, so the detrimental limits for SAR values listed previously should also apply to supplemental irrigation in humid regions. (See the recommendation in this section following the discussion of sodium hazard under Water Quality Considerations for Irrigation.)

Acidity and alkalinity. The only consideration not previously discussed relates to soil acidity, which is more prevalent in humid regions where supplemental irrigation is practiced. Any factor that drops the pH below 4.8 may render soluble toxic concentrations of iron, aluminum, and manganese. This might result from application of a highly acidic water or from a saline solution applied to an acidic soil. (See the recommendation in this section following the discussion of acidity and alkalinity under Water Quality Considerations for Irrigation.)

Trace elements. Criteria and related factors discussed in the section on Phytotoxic Trace Elements are equally applicable to supplemental irrigation in humid regions. Certain related qualifications must be kept in mind, however. First, foliar absorption of trace elements in toxic amounts is directly related to sprinkler irrigation. Critical levels established for soil or culture solutions would not apply to direct foliar injury. Regarding trace element concentrations in the soil resulting from irrigation water application, the vol of the water applied by sprinkler as supplemental irriga is much less than that applied by furrow or flood irriga in arid regions.

In assessing trace element concentrations in irriga water, total volume of water applied and the physicoch cal characteristics of the soil must be taken into consi tion. Both factors could result in different criteria for sup mental irrigation as compared with surface irrigation in regions.

Suspended solids. Certain factors regarding suspended s must be taken into consideration for sprinkler irriga The first deals with the plugging up of sprinkler nozzle these sediments. Size of sediment is a definite factor, no specific particle size limit can be established. If s larger sediment particles pass through the sprinkler, can often be washed off certain leafy vegetable crops. S of the finer fractions, suspended colloidal material, c accumulate on the leaves and, once dry, become extre difficult to wash off, thereby impairing the quality of product.

PHYTOTOXIC TRACE ELEMENTS

In addition to the effect of total salinity on plant gro individual ions may cause growth reductions. Ions of l major and trace elements occur in irrigation water. T elements are those that normally occur in waters or solutions in concentrations less than a few mg/l with u concentrations less than 100 microgram (μg)/l. Some r be essential for plant growth, while others are nonessen

When an element is added to the soil, it may com with it to decrease its concentration and increase the s of that element in the soil. If the process of adding irriga water containing a toxic level of the element continues, capacity of the soil to react with the element will saturated. A steady state may be approached in which amount of the element leaving the soil in the drainage wa equals the amount added with the irrigation water, with further change in concentration in the soil. Removai harvested crops can also be a factor in decreasing the cumulation of trace elements in soils.

In many cases, soils have high capacities to react w trace elements. Therefore, irrigation water containing tc levels of trace elements may be added for many years bef a steady state is approached. Thus, a situation exists wh toxicities may develop in years, decades, or even centu from the continued addition of pollutants to irrigat waters. The time would depend on soil and plant factors well as on the concentration of trace elements in the wa

Variability among species is well recognized. Recent vestigations by Foy et al. (1965),[402] and Kerridge et (1971)[425] working with soluble aluminum in soils and nutrient solutions, have demonstrated that there is a variability among varieties within a given species.

Comprehensive reviews of literature dealing with trace element effects on plants are provided by McKee and Wolf (1963),[436] Bolland and Butler (1966),[378] and Chapman (1966).[386] Hodgson (1963)[417] presented a review dealing with reactions of trace elements in soils.

In developing a workable program to determine acceptable limits for trace elements in irrigation waters, three considerations should be recognized:

- Many factors affect the uptake of and tolerance to trace elements. The most important of these are the natural variability in tolerances of plants and of animals that consume plants, in reactions within the soil, and in nutrient interactions, particularly in the plant.
- A system of tolerance limits should provide sufficient flexibility to cope with the more serious factors listed above.
- At the same time, restrictions must be defined as precisely as possible using presently available, but limited, research information.

Both the concentration of the element in the soil solution, assuming that steady state may be approached, and the total amount of the element added in relation to quantities that have been shown to produce toxicities were used in arriving at recommended maximum concentrations. A water application rate of 3 acre feet/acre/year was used to calculate the yearly rate of trace elements added in irrigation water.

The suggested maximum trace element concentrations for irrigation waters are shown in Table V-13.

The suggested maximum concentrations for continuous use on all soils are set for those sandy soils that have low capacities to react with the element in question. They are generally set at levels less than the concentrations that produce toxicities when the most sensitive plants are grown in nutrient solutions or sand cultures. This level is set, recognizing that concentration increases in the soil as water is evapotranspired, and that the effective concentration in the soil solution, at near steady state, is higher than in the irrigation water. The criteria for short-term use are suggested for soils that have high capacitites to remove from solution the element or elements being considered.

The work of Hodgson (1963)[417] showed that the general tolerance of the soil-plant system to manganese, cobalt, zinc, copper, and boron increased as the pH increased, primarily because of the positive correlation between the capacity of the soil to inactivate these ions and the pH. This same relationship exists with aluminum and probably exists with other elements such as nickel (Pratt et al. 1964)[449] and boron (Sims and Bingham 1968).[465] However, the ability of the soil to inactivate molybdenum decreases with increase in pH, such that the amount of this element that could be added without producing excesses was higher in acid soils.

TABLE V-13—Recommended Maximum Concentrations of Trace Elements in Irrigation Waters[a]

Element	For waters used continuously on all soil mg/l	For use up to 20 years on fine textured soils of pH 6.0 to 8.5 mg/l
Aluminum	5.0	20.0
Arsenic	0.10	2.0
Beryllium	0.10	0.50
Boron	0.75	2.0
Cadmium	0.010	0.050
Chromium	0.10	1.0
Cobalt	0.050	5.0
Copper	0.20	5.0
Fluoride	1.0	15.0
Iron	5.0	20.0
Lead	5.0	10.0
Lithium	2.5[b]	2.5[b]
Manganese	0.20	10.0
Molybdenum	0.010	0.050[d]
Nickel	0.20	2.0
Selenium	0.020	0.020
Tin[c]		
Titanium[c]		
Tungsten[c]		
Vanadium	0.10	1.0
Zinc	2.0	10.0

[a] These levels will normally not adversely affect plants or soils.

[b] Recommended maximum concentration for irrigating citrus is 0.075 mg/l.

[c] See text for a discussion of these elements.

[d] For only acid fine textured soils or acid soils with relatively high iron oxide contents.

In addition to pH control (i.e., liming acid soils), another important management factor that has a large effect on the capacity of soils to adsorb some trace elements without development of plant toxicities is the available phosphorus level. Large applications of phosphate are known to induce deficiencies of such elements as copper and zinc and greatly reduce aluminum toxicity (Chapman 1966).[386]

The concentrations given in Table V-13 are for ionic and soluble forms of the elements. If insoluble forms are present as particulate matter, these should be removed by filtration before the water is analyzed.

Aluminum

The toxicity of this ion is considered to be one of the main causes of nonproductivity in acid soils (Coleman and Thomas 1967,[392] Reeve and Sumner 1970,[453] Hoyt and Nyborg 1971a[419]).

At pH values from about 5.5 to 8.0, soils have great capacities to precipitate soluble aluminum and to eliminate its toxicity. Most irrigated soils are naturally alkaline, and many are highly buffered with calcium carbonate. In these situations aluminum toxicity is effectively prevented.

With only a few exceptions, as soils become more acid ($pH < 5.5$), exchangeable and soluble aluminum develop by dissolution of oxides and hydroxides or by decomposition of clay minerals. Thus, without the introduction of aluminum, a toxicity of this element usually develops as soils are acidified, and limestone must be added to keep the soil productive.

In nutrient solutions toxicities are reported for a number of plants at aluminum concentrations of 1 mg/l (Pratt 1966),[448] whereas wheat is reported to show growth reductions at 0.1 mg/l (Barnette 1923).[370] Liebig et al. (1942)[432] found growth depressions of orange seedlings at 0.1 mg/l. Ligon and Pierre (1932)[433] showed growth reductions of 60, 22, and 13 per cent for barley, corn, and sorghum, respectively, at 1 mg/l.

In spite of the potential toxicity of aluminum, this is not the basis for the establishment of maximum concentrations in irrigation waters, because ground limestone can be added where needed to control aluminum solubility in soils. Nevertheless, two disadvantages remain. One is that the salts that are the sources of soluble aluminum in waters acidify the soil and contribute to the requirement for ground limestone to prevent the accumulation or development of soluble aluminum. This is a disadvantage only in acid soils. The other disadvantage is a greater fixation of phosphate fertilizer by freshly precipitated aluminum hydroxides.

In determining a recommendation for maximum levels of aluminum in irrigation water using 5.0 mg/l for waters to be used continuously on all soils and 20 mg/l for up to 20 years on fine-textured soils, the following was considered. At rates of 3 acre feet of water per acre per year the calcium carbonate equivalent of the 5 mg/l concentration used for 100 years would be 11.5 tons per acre; the 20 mg/l concentration for 20 years would be equivalent to 9 tons of $CaCO_3$ per acre. In most irrigated soils this amount of limestone would not have to be added, because the soils have sufficient buffer capacity to neutralize the aluminum salts. In acid soils that are already near the pH where limestone should be used, the aluminum added in the water would contribute these quantities to the lime requirements.

Amounts of limestone needed for control of soluble aluminum in acid soils can be estimated by a method that is based on pH control (Shoemaker et al. 1961).[463] A method based on the amount of soluble and exchangeable aluminum was developed by Kamprath (1970).[424]

Recommendations

Recommended maximum concentrations are 5.0 mg/l aluminum for continuous use on all soils and 20 mg/l for use on fine textured neutral to alkaline soils over a period of 20 years.

Arsenic

Albert and Arndt (1931)[368] found that arsenic at 0.5 mg/l in nutrient solutions reduced the growth of roots of cowpeas, and at 1.0 mg/l it reduced the growth of both roots and tops. They reported that 1.0 mg/l of soluble arsenic was frequently found in the solution obtained from soils with demonstrated toxic levels of arsenic. Rasmussen and Henry (1965)[451] found that arsenic at 0.5 mg/l in nutrient solutions produced toxicity symptoms in seedlings of the pineapple and orange. Below this concentration no symptom toxicity were found. Clements and Heggeness (1939)[390] ported that 0.5 mg/l arsenic as arsenite in nutrient s tions produced an 80 per cent yield reduction in tomat Liebig et al. (1959)[431] found that 10 mg/l of arsenic arsenate or 5 mg/l as arsenite caused marked reduct in growth of tops and roots of citrus grown in nutrient s tions. Machlis (1941)[434] found that concentrations of 1.2 12 mg/l caused growth suppression in beans and sudan g respectively.

However, the most definite work with arsenic toxicity soils has been aimed at determining the amounts that be added to various types of soils without reduction in yie of sensitive crops. The experiments of Cooper et al. (1932) Vandecaveye et al. (1936),[472] Crafts and Rosenfels (1939) Dorman and Colman (1939),[396] Dorman et al. (1939) Clements and Munson (1947),[391] Benson (1953),[372] Cl holm et al. (1955),[388] Jacobs et al. (1970),[422] Woolson et (1971)[481] showed that the amount of total arsenic that p duced the initiation of toxicity varied with soil texture a other factors that influenced the adsorptive capacity. suming that the added arsenic is mixed with the surface inches of soil and that it is in the arsenate form, the amou that produce toxicity for sensitive plants vary from 1 pounds (lb)/acre for sandy soils to 300 lb/acre for clay soils. Data from Crafts and Rosenfels (1939)[394] for 80 sc showed that for a 50 per cent yield reduction with barl 120, 190, 230, and 290 lb arsenic/acre were required i sandy loams, loams, clay loams, and clays, respective These amounts of arsenic indicated the amounts adsorb into soils of different adsorptive capacities before the toxici level was reached.

With long periods of time involved, such as would be t case with accumulations from irrigation water, possib leaching in sandy soils (Jacobs et al. 1970)[422] and reversi to less soluble and less toxic forms of arsenic (Crafts a Rosenfels 1939)[394] allow extensions of the amounts requir for toxicity. Perhaps a factor of at least two could be use giving a limit of 200 lb in sandy soils and a limit of 600 in clayey soils over many years. Using these limits, a co centration of 0.1 mg/l could be used for 100 years on san soils, and a concentration of 2 mg/l used for a period of 2 years or 0.5 mg/l used for 100 years on clayey soils woul provide an adequate margin of safety. This is assuming acre feet of water are used per acre per year (1 mg/l equa 2.71 lb/acre foot of water or 8.13 lb/3 acre feet), and tha the added arsenic becomes mixed in a 6-inch layer of soi Removal of small amounts in harvested crops provides a additional safety factor.

The only effective management practice known for soil that have accumulated toxic levels of arsenic is to change t more tolerant crops. Benson and Reisenauer (1951)[37 developed a list of plants of three levels of tolerance. Wor by Reed and Sturgis (1936)[452] suggested that rice on floode soils was extremely sensitive to small amounts of arsenic, an that the suggested maximum concentrations listed below were too high for this crop.

Recommendations

Recommendations are that maximum concentrations of arsenic in irrigation water be 0.10 mg/l for continuous use on all soils and 2 mg/l for use up to 20 years on fine textured neutral to alkaline soils.

Beryllium

Haas (1932)[408] reported that some varieties of citrus seedlings showed toxicities at 2.5 mg/l of beryllium whereas others showed toxicity at 5 mg/l in nutrient solutions. Romney et al. (1962)[455] found that beryllium at 0.5 mg/l in nutrient solutions reduced the growth of bush beans. Romney and Childress (1965)[454] found that 2 mg/l or greater in nutrient solutions reduced the growth of tomatoes, peas, soybeans, lettuce, and alfalfa plants. Additions of soluble beryllium salts at levels equivalent to 4 per cent of the cation-adsorption capacity of two acid soils reduced the yields of ladino clover. Beryllium carbonate and beryllium oxide at the same levels did not reduce yields. These results suggest that beryllium in calcareous soils might be much less active and less toxic than in acid soils. Williams and LeRiche (1968)[480] found that beryllium at 2 mg/l in nutrient solutions was toxic to mustard, whereas 5 mg/l was required for growth reductions with kale.

It seems reasonable to recommend low levels of beryllium in view of the fact that, at 0.1 mg/l, 80 pounds of beryllium would be added in 100 years using 3 acre feet of water per acre per year. In 20 years, at 0.5 mg/l, water at the same rate would add 80 pounds.

Recommendations

In view of toxicities in nutrient solutions and in soils, it is recommended that maximum concentrations of beryllium in irrigation waters be 0.10 mg/l for continuous use on all soils and 0.50 mg/l for use on neutral to alkaline fine textured soils for a 20-year period.

Boron

Boron is an essential element for the growth of plants. Optimum yields of some plants are obtained at concentrations of a few tenths mg/l in nutrient solutions. However, at concentrations of 1 mg/l, boron is toxic to a number of sensitive plants. Eaton (1935,[400] 1944[401]) determined the boron tolerance of a large number of plants and developed lists of sensitive, semitolerant, and tolerant species. These lists, slightly modified, are also given in the U.S.D.A. Handbook 60 (Salinity Laboratory 1954)[459] and are presented in Table V-14. In general, sensitive crops showed toxicities at 1 mg/l or less, semitolerant crops at 1 to 2 mg/l, and tolerant crops at 2 to 4 mg/l. At concentrations above 4 mg/l, the irrigation water was generally unsatisfactory for most crops.

TABLE V-14—Relative Tolerance of Plants to Boron

(In each group the plants first named are considered as being more tolerant and the last named more sensitive.)

Tolerant	Semitolerant	Sensitive
Athel (Tamarix asphylla)	Sunflower (native)	Pecan
Asparagus	Potato	Black Walnut
Palm (Phoenix canariensis)	Acala cotton	Persian (English) walnut
Date palm (P. dactylifera)	Pima cotton	Jerusalem artichoke
Sugar beet	Tomato	Navy bean
Mangel	Sweetpea	American elm
Garden beet	Radish	Plum
Alfalfa	Field pea	Pear
Gladiolus	Ragged Robin rose	Apple
Broadbean	Olive	Grape (Sultanina and Malaga)
Onion	Barley	Kadota fig
Turnip	Wheat	Persimmon
Cabbage	Corn	Cherry
Lettuce	Milo	Peach
Carrot	Oat	Apricot
	Zinnia	Thornless blackberry
	Pumpkin	Orange
	Bell pepper	Avocado
	Sweet potato	Grapefruit
	Lima bean	Lemon

Salinity Laboratory Staff 1954[459].

Bradford (1966),[379] in a review of boron deficiencies and toxicities, stated that when the boron content of irrigation waters was greater than 0.75 mg/l, some sensitive plants, such as citrus, begin to show injury. Chapman (1968)[387] concluded that citrus showed some mild toxicity symptoms when irrigation waters have 0.5 to 1.0 mg/l, and that when the concentration was greater than 10 mg/l pronounced toxicities were found.

Biggar and Fireman (1960)[375] and Hatcher and Bower (1958)[411] showed that the accumulation of boron in soils is an adsorption process, and that before soluble levels of 1 or 2 mg/l can be found, the adsorptive capacity must be saturated. With neutral and alkaline soils of high adsorption capacities water of 2 mg/l might be used for some time without injury to sensitive plants.

Recommendations

From the extensive work on citrus, one of the most sensitive crops, the maximum concentration of 0.75 mg boron/l for use on sensitive crops on all soils seems justified. Recommended maximum concentrations for semitolerant and tolerant plants are considered to be 1 and 2 mg/l respectively.

For neutral and alkaline fine textured soils the recommended maximum concentration of boron in irrigation water used for a 20-year period on sensitive crops is 2.0 mg/l. With tolerant plants or for shorter periods of time higher boron concentrations are acceptable.

Cadmium

Data by Page et al. *in press* (1972)[444] showed that the yields of beans, beets, and turnips were reduced about 25 per cent by 0.10 mg cadmium/l in nutrient solutions: whereas cabbage and barley gave yield decreases of 20 to 50 per cent at 1.0 mg/l. Corn and lettuce were intermediate in response with less than 25 per cent yield reductions at 0.10 mg/l and greater than 50 per cent at 1.0 mg/l. Cadmium contents of plants grown in soils containing 0.11 to 0.56 mg/l acid extractable cadmium (Lagerwerff 1971)[427] were of the same order of magnitude as the plants grown by Page et al. in control nutrient solutions.

Because of the phytotoxicity of cadmium to plants, its accumulation in plants, lack of soils information, and the potential problems with this element in foods and feeds, a conservative approach is taken.

Recommendations

Maximum concentrations for cadmium in irrigation waters of 0.010 mg/l for continuous use on all soils and 0.050 mg/l on neutral and alkaline fine textured soils for a 20-year period are recommended.

Chromium

Even though a number of investigators have found small increases in yields with small additions of this element, it has not become recognized as an essential element. The primary concern of soil and plant scientists is with its toxicity. Soane and Saunders (1959)[466] found that 10 mg/l of chromium in sand cultures was toxic to corn, and that for tobacco 5 mg/l of chromium caused reduced growth and 1.0 mg/l reduced stem elongation. Scharrer and Schropp (1935)[461] found that chromium, as chromic sulfate, was toxic to corn at 5 mg/l in nutrient solutions. Hewitt (1953)[412] found that 8 mg/l chromium as chromic or chromate ions produced iron chlorosis on sugar beets grown in sand cultures. Hewitt also found that the chromate ion was more toxic than the chromic ion. Hunter and Vergnano (1953)[421] found that 5 mg/l of chromium in nutrient solutions produced iron deficiencies in plants. Turner and Rust (1971)[470] found that chromium treatments as low as 0.5 mg/l in water cultures and 10 mg/kg in soil cultures significantly reduced the yields of two varieties of soybeans.

Because little is known about the accumulation of chromium in soils in relation to its toxicity, a concentration of less than 1.0 mg/l in irrigation waters is desirable. At this concentration, using 3 acre feet water/acre/yr, more than 80 lb of chromium would be added per acre in 100 years, and using a concentration of 1.0 mg/l for a period of 20 years and applying water at the same rate, about 160 pounds of chromium would be added to the soil.

Recommendations

In view of the lack of knowledge concernin chromium accumulation and toxicity, a maximu concentration of 0.1 mg/l is recommended for continuous use on all soils and 1.0 mg/l on neutr and alkaline fine textured soils for a 20-year perio is recommended.

Cobalt

Ahmed and Twyman (1953)[365] found that tomato plan showed toxicity from cobalt at 0.1 mg/l, and Vergnan and Hunter (1953)[475] found that cobalt at 5 mg/l was high toxic to oats. Scharrer and Schropp (1933)[460] found th cobalt at a few mg/l in sand and solution cultures was tox to peas, beans, oats, rye, wheat, barley, and corn, and th the tolerance to cobalt increased in the order listed. Vans low (1966a)[473] found additions of 100 mg/kg to soils wer not toxic to citrus.

The literature indicates that a concentration of 0.10 mg for cobalt is near the threshold toxicity level in nutrien solutions. Thus, a concentration of 0.05 mg/l appears to b satisfactory for continuous use on all soils. However, becaus the reaction of this element with soils is strong at neutra and alkaline pH values and it increases with time (Hodgso 1960),[416] a concentration of 5.0 mg/l might be tolerated b fine textured neutral and alkaline soils when it is added i small yearly increments.

Recommendations

Recommended maximum concentrations for cobalt are set at 0.050 mg/l for continuous use on all soils and 5.0 mg/l for neutral and alkaline fine textured soils for a 20-year period.

Copper

Copper concentrations of 0.1 to 1.0 mg/l in nutrient solutions have been found to be toxic to a large number o plants (Piper 1939,[447] Liebig et al. 1942,[432] Frolich et al. 1966,[403] Nollendorfs 1969,[442] Struckmeyer et al. 1969,[40 Seillac 1971[462]). Westgate (1952)[476] found copper toxicity in soils that had accumulated 800 lb acre from the use of Bordeaux sprays. Field studies in sandy soils of Florida (Reuther and Smith 1954)[457] showed that toxicity to citrus resulted when copper levels reached 1.6 mg/meq of cation-exchange capacity per 100 g of dry soil.

The management procedures that reduce copper toxicity include liming the soil if it is acid, using ample phosphate fertilizer, and adding iron salts (Reuther and Labanauskas 1966).[456]

Toxicity levels in nutrient solutions and limited data on soils suggest a concentration of 0.20 mg/l for continuous use on all soils. This level used at a rate of 3 acre feet of water per year would add about 160 pounds of copper in 100 years, which is approaching the recorded levels of toxicity in acid sandy soils. A safety margin can be obtained by liming these soils. A concentration of copper at 5.0 mg/l applied in irrigation water at the rate of 3 acre feet of water per year for a 20-year period would add 800 pounds of copper in 20 years.

Recommendations

Based on toxicity levels in nutrient solutions and the limited soils data available, a maximum concentration of 0.20 mg/l copper is recommended for continuous use on all soils. On neutral and alkaline fine textured soils for use over a 20-year period, a maximum concentration of 5.0 mg/l is recommended.

Fluoride

Applications of soluble fluoride salts to acid soils can produce toxicity to plants. Prince et al. (1949)[450] found that 360 pounds fluoride per acre, added as sodium fluoride, reduced the yields of buckwheat at pH 4.5, but at pH values above 5.5 this rate produced no injury.

MacIntire et al. (1942)[435] found that 1,150 pounds of fluoride in superphosphate, 575 pounds of fluoride in slag, or 2,300 pounds of fluoride as calcium fluoride per acre had no detrimental effects on germination or plant growth on well-limed neutral soils, and that vegetation grown on these soils showed only a slight increase in fluoride as compared to those grown in acid soils. However, Shirley et al. (1970)[464] found that bones of cows that had grazed pastures fertilized with raw rock and colloidal phosphate, which contained approximately two to three per cent fluorides, for seven to 16 years averaged approximately 2,900 and 2,300 mg of fluorine per kilogram of bone, respectively. The bones of cows that had grazed on pastures fertilized with relatively fluorine free superphosphate, concentrated superphosphate, and basic slag fertilizer contained only 1400 mg/kg fluorine.

Recommendations

Because of the capacity of neutral and alkaline soils to inactivate fluoride, a relatively high maximum concentration for continuous use on these soils is recommended. Recommended maximum concentrations are 1.0 mg/l for continuous use on all soils and 15 mg/l for use for a 20-year period on neutral and alkaline fine textured soils.

Iron

Iron in irrigation waters is not likely to create a problem of plant toxicities. It is so insoluble in aerated soils at all pH values in which plants grow well, that it is not toxic. In fact, the problems with this element are deficiencies in alkaline soils. In reduced (flooded) soils soluble ferrous ions develop from inherent compounds in soils, so that quantities that might be added in waters would be of no concern. However, Rhoads (1971)[458] found large reductions in the quality of cigar wrapper tobacco when plants were sprinkler irrigated with water containing 5 or more mg soluble iron/l, because of precipitation of iron oxides on the leaves. Rhoad's experience would suggest caution when irrigating any crops using sprinkler systems and waters having sufficient reducing conditions to produce reduced and soluble ferrous iron.

The disadvantages of soluble iron salts in waters are that these would contribute to soil acidification, and the precipitated iron would increase the fixation of such essential elements as phosphorous and molybdenum.

Recommendations

A maximum concentration of 5.0 mg/l is recommended for continuous use on all soils, and a maximum concentration of 20 mg/l is recommended on neutral to alkaline soils for a 20-year period. The use of waters with large concentrations of suspended freshly precipitated iron oxides and hydroxides is not recommended, because these materials also increase the fixation of phosphorous and molybdenum.

Lead

The phytotoxicity of lead is relatively low. Berry (1924)[374] found that a concentration of lead nitrate of 25 mg/l was required for toxicity to oats and tomato plants. At a concentration of 50 mg/l, death of plants occurred. Hopper (1937)[418] found that 30 mg/l of lead in nutrient solutions was toxic to bean plants. Wilkins (1957)[479] found that lead at 10 mg/l as lead nitrate reduced root growth. Since soluble lead contents in soils were usually from 0.05 to 5.0 mg/kg (Brewer 1966),[383] little toxicity can be expected. It was shown that the principal entry of lead into plants was from aerial deposits rather than from absorption from soils (Page et al. 1971)[445] indicating that lead that falls onto the soil is not available to plants.

In a summary on the effects of lead on plants, the Committee on the Biological Effects of Atmosphere Pollutants (NRC 1972)[441] concluded that there is not sufficient evidence to indicate that lead, as it occurs in nature, is toxic to vegetation. However, in studies using roots of some plants and very high concentrations of lead, this element was reported to be concentrated in cell walls and nuclei during mitosis and to inhibit cell proliferation.

Recommendations

Recommended maximum concentrations of lead are 5.0 mg/l for continuous use on all soils and 10 mg/l for a 20-year period on neutral and alkaline fine textured soils.

Lithium

Most crops can tolerate lithium in nutrient solutions at concentrations up to 5 mg/l (Oertli 1962,[443] Bingham et al. 1964,[377] Bollard and Butler 1966[378]). But research revealed that citrus was more sensitive (Aldrich et al. 1951,[369] Bradford 1963b,[381] Hilgeman et al. 1970[415]). Hilgeman et al. (1970)[415] found that grapefruit developed severe symptoms of lithium toxicity when irrigated with waters containing lithium at 0.18 to 0.25 mg/l. Bradford (1963a)[380] reported that experience in California indicated slight toxicity of lithium to citrus at 0.06 to 0.10 mg/l in the water.

Lithium is one of the most mobile of cations in soils. It tends to be replaced by other cations in waters or fertilizers and is removed by leaching. On the other hand, it is not precipitated by any known process.

Recommendations

Recommendations for maximum concentrations of lithium, based on its phytotoxicity, are 2.5 mg/l for continuous use on all soils, except for citrus where the recommended maximum concentration is 0.075 mg/l for all soils. For short-term use on fine textured soils the same maximum concentrations are recommended because of lack of inactivation in soils.

Manganese

Manganese concentrations at a few tenths to a few milligrams per liter in nutrient solutions are toxic to a number of crops as shown by Morris and Pierre (1949),[440] Adams and Wear (1957),[364] Hewitt (1965),[414] and others. However, toxicities of this element are associated with acid soils, and applications of proper quantities of ground limestone successfully eliminated the problem. Increasing the pH to the 5.5 to 6.0 range usually reduced the active manganese to below the toxic level (Adams and Wear 1957).[364] Hoyt and Nyborg (1971b)[420] found that available manganese in the soil and manganese content of plants were negatively correlated with soil pH. However, the definite association of toxicity with soil pH as found with aluminum was not found with manganese, which has a more complex chemistry. Thus, more care must be taken in setting water quality criteria for manganese than for aluminum (i.e., management for control of toxicities is not certain).

Recommendations

Recommended maximum concentrations for manganese in irrigation waters are set at 0.20 mg/l for continued use on all soils and 10 mg/l for use up to 20 years on neutral and alkaline fine textured soils. Concentrations for continued use can be increased with alkaline or calcareous soils, and also with crops that have higher tolerance levels.

Molybdenum

This element presents no problems of toxicity to plants at concentrations usually found in soils and waters. The problem is one of toxicity to animals from molybdenum ingested from forage that has been grown in soils with relatively high amounts of avaiable molybdenum. Dye O'Hara (1959)[398] reported that the molybdenum concer tion in forage that produced toxicity in ruminants was 30 mg/kg. Lesperance and Bohman (1963)[430] found toxicity was not simply associated with the molybde content of forage but was influenced by the amoun other elements, particularly copper. Jensen and Lesper (1971)[423] found that the accumulation of molybdenur plants was proportional to the amount of the element ac to the soil.

Kubota et al. (1963)[426] found that molybdenum con trations of 0.01 mg/l or greater in soil solutions were sociated with animal toxicity levels of this element in ai clover. Bingham et al. (1970)[376] reported that molybdosi cattle was associated with soils that had 0.01 to 0.10 n of molybdenum in saturation extracts of soils.

Recommendations

The recommended maximum concentration molybdenum for continued use of water on soils, based on animal toxicities from forage, 0.010 mg/l. For short term use on soils that re with this element, a concentration of 0.050 m is recommended.

Nickel

According to Vanselow (1966b),[474] many experime with sand and solution cultures have shown that nickel 0.5 to 1.0 mg/l is toxic to a number of plants. Chang a Sherman (1953)[385] found that tomato seedlings were jured by 0.5 mg/l. Millikan (1949)[437] found that 0.5 to mg/l were toxic to flax. Brenchley (1938)[382] reported tox ity to barley and beans from 2 mg/l. Crooke (1954 found that 2.5 mg/l was toxic to oats. Legg and Ormer (1958)[429] found that 1.0 mg/l produced toxicity in h plants. Vergnano and Hunter (1953)[475] found that 1.0 m in solutions flushed through sand cultures was toxic to oa Soane and Saunders (1959)[466] found that tobacco pla showed no toxicity at 30 mg/l, and that corn showed toxicity at 2 mg/l but showed toxicity at 10 mg/l.

Work by Mizuno (1968)[439] and Halstead et al. (1969) and the review of Vanselow (1966b)[474] showed that increa ing the pH of soils reduces the toxicity of added nickel.

Halstead et al. (1969)[409] found the greatest capacity to a sorb nickel without development of toxicity was by a s with 21 per cent organic matter.

Recommendations

Based on both toxicity in nutrient solutions an on quantities that produce toxicities in soils, th recommended maximum concentration of nick in irrigation waters is 0.20 mg/l for continued us on all soils. For neutral fine textured soils for period up to 20 years, the recommended maximun is 2.0 mg/l.

Selenium

Selenium is toxic at low concentrations in nutrient solutions, and only small amounts added to soils increase the selenium content of forages to a level toxic to livestock. Broyer et al. (1966)[384] found that selenium at 0.025 mg/l in nutrient solutions decreased the yields of alfalfa.

The best evidence for use in setting water quality criteria for this element is application rates in relation to toxicity in forages. Amounts of selenium in forages required to prevent selenium deficiencies in cattle (Allaway et al. 1967)[366] ranged between 0.03 and 0.10 mg/kg (depending on other factors), whereas concentrations above 3 or 4 mg/kg were considered toxic (Underwood 1966).[471] A number of investigators (Hamilton and Beath 1963,[410] Grant 1965,[407] Allaway et al. 1966)[367] have shown that small applications of selenium to soils at a rate of a few kilograms per hectare produced plant concentrations of selenium that were toxic to animals. Gissel-Nielson and Bisbjerg (1970)[406] found that applications of approximately 0.2 kg/hectare of selenium produced from 1.0 to 10.5 mg/kg in tissues of forage and vegetable crops.

Recommendation

With the low levels of selenium required to produce toxic levels in forages, the recommended maximum concentration in irrigation waters is 0.02 mg/l for continuous use on all soils. At a rate of 3 acre feet of water per acre per year this concentration represents 3.2 pounds per acre in 20 years. The same recommended maximum concentration should be used on neutral and alkaline fine textured soils until greater information is obtained on soil reactions. The relative mobility of this element in soils in comparison to other trace elements and slow removal in harvested crops provide a sufficient safety margin.

Tin, Tungsten, and Titanium

Tin, tungsten, and titantium are effectively excluded by plants. The first two can undoubtedly be introduced to plants under conditions that can produce specific toxicities. However, not enough is known at this time about any of the three to prescribe tolerance limits. (This is true with other trace elements such as silver.) Titantium is very insoluble, at present it is not of great concern.

Vanadium

Gericke and Rennenkampff (1939)[405] found that vanadium at 0.1, 1.0, and 2.0 mg/l added to nutrient solutions as calcium vanadate slightly increased the growth of barley, whereas at 10 mg/l vanadium was toxic to both tops and roots and that vanadium chloride at 1.0 mg/l of vanadium was toxic. Warington (1954,[476] 1956[477]) found that flax, soybeans, and peas showed toxicity to vanadium in the concentration range of 0.5 to 2.5 mg/l. Chiu (1953)[389] found that 560 pounds per acre of vanadium added as ammonium metavanadate to rice paddy soils produced toxicity to rice.

Recommendations

Considering the toxicity of vanadium in nutrient solutions and in soils and the lack of information on the reaction of this element with soils, a maximum concentration of 0.10 mg/l for continued use on all soils is recommended. For a 20-year period on neutral and alkaline fine textured the recommended maximum concentration is 1.0 mg/l.

Zinc

Toxicities of zinc in nutrient solutions have been demonstrated for a number of plants. Hewitt (1948)[413] found that zinc at 16 to 32 mg/l produced iron deficiencies in sugar beets. Hunter and Vergnano (1953)[421] found toxicity to oats at 25 mg/l. Millikan (1947)[438] found that 2.5 mg/l produced iron deficiency in oats. Earley (1943)[399] found that the Peking variety of soybeans was killed at 0.4 mg/l, whereas the Manchu variety was killed at 1.6 mg/l.

The toxicity of zinc in soils is related to soil pH, and liming acid soil has a large effect in reducing toxicity (Barnette 1936,[371] Gall and Barnette 1940,[404] Peech 1941,[446] Staker and Cummings 1941,[468] Staker 1942,[467] Lee and Page 1967[423]). Amounts of added zinc that produce toxicity are highest in clay and peat soils and smallest in sands.

On acid sandy soils the amounts required for toxicity would suggest a recommended maximum concentration of zinc of 1 mg/l for continuous use. This concentration at a water application rate of 3 acre feet/acre/year would add 813 pounds per acre in 100 years. However, if acid sandy soils are limed to pH values of six or above, the tolerance level is increased by at least a factor of two (Gall and Barnette 1940).[404]

Recommendations

Assuming adequate use of liming materials to keep pH values high (six or above), the recommended maximum concentration for continuous use on all soils is 2.0 mg/l. For a 20-year period on neutral and alkaline soils the recommended maximum is 10 mg/l. On fine textured calcareous soils and on organic soils, the concentrations can exceed this limit by a factor of two or three with low probability of toxicities in a 20-year period.

PESTICIDES (IN WATER FOR IRRIGATION)

Pesticides are used widely in water for irrigation on commercial crops in the United States (Sheets 1967).[502] Figures on production, acreage treated, and use patterns indicate insecticides and herbicides comprise the major agricultural pesticides. There are over 320 insecticides and 127 herbicides registered for agricultural use (Fowler 1972).[498]

Along with the many benefits to agriculture, pesticides can have detrimental effects. Of concern for irrigated agriculture is the possible effects of pesticide residues in irrigation water on the growth and market quality of forages and crops. Pesticides most likely to be found in agricultural water supplies are listed in the Freshwater Appendix II-D.

Insecticides in Irrigation Water

The route of entry of insecticides into waters is discussed in the pesticide section under Water for Livestock Enterprises. For example, Miller et al. (1967)[500] observed the movement of parathion from treated cranberry bogs into a nearby irrigation ditch and drainage canal, and Sparr et al. (1966)[503] monitored endrin in waste irrigation water used three days after spraying. In monitoring pesticides in water used to irrigate areas near Tule Lake and lower Klamath Lake Wildlife Refuges in northern California, Godsil and Johnson (1968)[499] detected high levels of endrin compared to other pesticides. They observed that the concentrations of pesticides in irrigation waters varied directly with agricultural activities.

In monitoring pesticides residues from 1965 to 1967 (Agricultural Research Service 1969a),[483] the U. S. Department of Agriculture detected the following pesticides in irrigation waters at a sampling area near Yuma, Arizona: the DDT complex, dieldrin, methyl parathion, endrin, endosulfan, ethyl parathion, dicofol, s,s,s,-tributyl phosphorotrithiate (DEF), and demeton. Insecticides most commonly detected were DDT, endrin, and dieldrin. For the most part, all residues in water were less than 1.0 μg/l. A further examination of the irrigation water at the Yuma sampling area showed that water entering it contained relatively low amounts of insecticide residues while water leaving contained greater concentrations. It was concluded that some insecticides were picked up from the soil by irrigation water and carried out of the fields.

Crops at the same location were also sampled for insecticide residues. With the exception of somewhat higher concentrations of DDT and dicofol in cotton stalks and cantaloupe vines, respectively, residues in crop plants were relatively small. The mean concentrations, where detected, were 2.6 μg/g combined DDT, 0.01 μg/g endrin, 0.40 μg/g dieldrin, 0.05 μg/g lindane, 5.0 μg/g dicofol, and 1.8 μg/g combined parathion. The larger residues for DDT and dicofol were apparently from foliage applications. Sampling of harvested crops showed that residues were generally less than 0.30 μg/g and occurred primarily in lettuce and in cantaloupe pulp, seeds, and rind. DDT, dicofol, and endrin were applied to crops during the survey, and from 2.0 to 6.0 lb/acre of DDT were applied to the soil before 1965.

Some crops do not absorb measurable amounts of insecticides but others translocate the chemicals in various amounts. At the levels (less than 1.0 μg/l) monitored by the U. S. Department of Agriculture in irrigation waters (Agricultural Research Service 1969a),[483] there is little evidence indicating that insecticide residues in the water are d
mental to plant growth or accumulate to undesirable c
legal concentrations in food or feed crops.

Herbicides in Irrigation Water

In contrast to insecticides, misuse of herbicides can
sent a greater hazard to crop growth. Herbicides are li
to be found in irrigation water under the following circ
stances: (1) during their purposeful introduction into irr
tion water to control submersed weeds; of (2) incidenta
herbicide treatment for control of weeds on banks of irr
tion canals. Attempts are seldom made to prevent w
containing herbicides such as xylene or acrolein from b
diverted onto cropland during irrigation. In most instan
however, water-use restrictions do apply when herbic.
are used in reservoirs of irrigation water. The herbic
used in reservoirs are more persistent and inherently m
phytotoxic at low levels than are xylene and acrolein.

The tolerances of a number of crops to various herbici
used in and around water are listed in Table V-15. Resi
levels tolerated by most crops are usually much higher t
the concentrations found in water following normal us
the herbicides. Aromatic solvent (xylene) and acrolein
widely used in western states for keeping irrigation car
free of submersed weeds and algae and are not harmful
crops at concentrations needed for weed control. (U.
Department of Agriculture, Agricultural Research Serv
1963,[501] hereafter referred to as Agricultural Resear
Service 1963).[482] Xylene, which is non-polar, is lost rapi
from water (50 per cent in 3 to 4 hours) by volatility (Fra
et al. 1970).[497] Acrolein, a polar compound, may remain
flowing water for periods of 24 hours or more at levels t
are phytotoxic only to submersed aquatic weeds. Cop
sulfate is used frequently to control algae. It has also be
found effective on submersed vascular weeds when appli
continuously to irrigation water at low levels (Bartl
1969).[487]

The herbicides that have been used most widely on irrig
tion ditchbanks are 2,4-D, dalapon, TCA, and silvex. T
application of herbicides may be restricted to a swath of
few feet along the margin of the water, or it may cover
swath 15 feet or more wide. A variable overlap of the spr
pattern at the water margin is unavoidable and accoun
for most of the herbicide residues that occur in water durir
ditchbank treatments. Rates of application vary from 2
per acre for 2,4-D to 20 lb per acre for dalapon. For e
amples of residue levels that occur in water from the
treatments see Table V-16. The residues generally occur onl
during the periods when ditchbanks are treated.

The rates of dissipation of herbicides in irrigation wate
were reported recently by Frank et al. (1970).[497] The herbi
cides and formulations commonly used on ditchbanks ar
readily soluble in water and not extensively sorbed to soi
or other surfaces. Reduction in levels of residues in flowin
irrigation water is due largely to dilution. Irrigation canal

TABLE V-15—Tolerance of Crops to Various Herbicides Used In and Around Waters[a]

Herbicide	Site of use	Formulation	Treatment rate	Concentration that may occur in irrigation water[b]	Crop injury threshold in irrigation water (mg/l)[c]
Acrolein	Irrigation canals	Liquid	15 mg/l for 4 hours	10 to 0.1 mg/l	Flood or furrow: beans-60, corn-60, cotton-80, soybeans-20, sugar beets-60.
			0.6 mg/l for 8 hours	0.4 to 0.02 mg/l	Sprinkler: corn-60, soybeans-15, sugar beets-15.
			0.1 mg/l for 48 hours	0.05 to 0.1 mg/l	
Aromatic solvents (xylene)	Flowing water in canals or drains.	Emulsifiable liquid	5 to 10 gal/cfs (350 to 750 mg/l) applied in 30–60 minutes	700 mg/l or less	Alfalfa > 1,600, beans-1,200, carrots-1,600, corn-3,000 cotton-1,600, grain sorghum > 800, oats-2,400, potatoes-1,300, wheat > 1,200.
Copper sulfate	Canals or reservoirs	Pentahydrate crystals.	Continuous treatment 0.5 to 3.0 mg/l, slug treatment-⅓ to 1 lb (0.15 to 0.45 kg) per cfs water flow	0.04 to 0.8 mg/l during first 10 miles, 0.08 to 9.0 mg/l during first 10 to 20 miles.	Threshold is above these levels.
Dalapon	Banks of canals and ditches	Water soluble salt	15 to 30 lb/A or 17 to 34 kg/ha	Less than 0.2 mg/l	Beets > 7.0, corn > 0.35
Diquat	Injected into water or sprayed over surface	Liquid	3 to 5 mg/l, 1 to 1.5 lbs/A, or 1.2 to 1.7 kg/ha	Usually less than 0.1 mg/l	Beans-5.0, corn-125
Diuron	Banks and bottoms of small dry powder ditches	Wettable powder	Up to 64 lb/A or 72 kg/ha	No data	No data
Dichlobenil	Bottoms of dry canals	Granules or wettable powder	7 to 10 lb/A or 7.9 to 12.6 kg/ha	No data	Alfalfa-10, corn > 10, soybeans-1.0, sugar beets-1.0 to 10.
Endothall	Ponds and reservoirs	Water soluble Na or K salts	1 to 4 mg/l	Absent or only traces	Corn-25, field beans-1.0, Alfalfa > 10.0
Endothall amine salts	Reservoirs and static-water canals	Liquid or granules	0.5 to 2.5 mg/l	Absent or only traces	Corn > 25, soybeans > 25, sugar beets-25
Fenac	Bottoms of dry canals	Liquid or granules	10 to 20 lb/A or 12.6 to 25.2 kg/ha	Absent or only traces	Alfalfa-1.0, corn-10, soybeans-0.1, sugar beets-0.1 to 10.
Monuron	Banks and bottoms of small dry powder ditches	Wettable powder	Up to 64 lb/A or 72 kg/ha	No data	No data
Silvex	Woody plants and brambles on floodways, along canal, stream, or reservoir banks	Esters in liquid form	2 to 4 lb/A or 2.2 to 4.4 kg/ha	No data. Probably well under 0.1 mg/l	Corn > 5.0, sugar beets and soybeans > 0.02.
	Floating and emersed weeds in southern waterways	"	2 to 8 lb/A or 2.2 to 8.8 kg/ha	0.01 to 1.6 mg/l 1 day after application	"
TCA	Banks of canals and ditches	Water soluble salt	Up to 64 lb/A or 72 kg/ha	Usually less than 0.1 mg/l	No injury observed at levels used.
2,4-D amine	On banks of canals and ditches	Liquid	1 to 4 lb/A or 1.1 to 4/4 kg/ha	0.01 to 0.10 mg/l	Field beans > 1.0, grapes-0.7, sugar beets > 0.2, soybeans > 0.02, corn-10, cucumbers, potatoes, sorghum, alfalfa, peppers > 1.0.
	Floating and emersed weeds in southern canals and ditches	"	2 to 4 lb/A or 2.2 to 4.4 kg/ha	No data. Probably less than 0.1 mg/l	"
Picloram	For control of brush on watersheds	Liquids or granules	1 to 3 lb/A or 1.1 to 3.3 kg/ha	No data	Corn > 10, field beans 0.1, sugar beets > 1.0

[a] Sources of data included in this table are: U.S. Department of Agriculture, Agricultural Research Service (1969)[505], Arle and McRae (1959,[485] 1960[486]), Bruns (1954,[489] 1957,[490] 1964,[491] 1969[492]), Bruns and Clore (1958),[493] Bruns and Dawson (1959),[494] Bruns et al. (1955,[495] 1964,[496] unpublished data 1971[508]) Frank et al. (1970),[497] Yeo (1959)[507].

[b] Herbicide concentrations given in this column are the highest concentrations that have been found in irrigation water, but these levels seldom remain in the water when it reaches the crop.

[c] Unless indicated otherwise, all crop tolerance data were obtained by flood or furrow irrigation. Threshold of injury is the lowest concentration causing temporary or permanent injury to crop plants even though, in many instances, neither crop yield nor quality was affected.

are designed to deliver a certain volume of water to be used on a specific area of cropland. Water is diverted from the canals at regular intervals, and this systematically reduces the volume of flow. Consequently, little or no water remains at the ends of most canals where disposal of water containing herbicides might be troublesome.

Residues in Crops

Successful application of herbicides for control of algae and submersed vascular weeds in irrigation channels is dependent upon a continuous flow of water. Because it is impractical to interrupt the flow and use of water during the application of herbicides in canals or on canal banks, the herbicide-bearing water is usually diverted onto croplands. Under these circumstances, measurable levels of certain herbicides may occur in crops.

Copper sulfate is used most frequently for control of algae at concentrations that are often less than the suggested tolerance for this herbicide in potable water. Application rates may range from one third pound of copper sulfate per cubic-feet-second (cfs) of water flow to two pounds per cfs of water flow (Agriculture Research Service 1963).[482] Xylene is a common formulating ingredient for many pesticides and as such is often applied directly to crop plants. The distribution by furrow or sprinkler of irrigation water containing acrolein contributes to the rapid loss of this herbicide. Copper sulfate, xylene, and acrolein are of minor importance as sources of objectionable residues in crops.

Phenoxy herbicides, dalapon, TCA, and amitrole are most persistent in irrigation water (Bartley and Hattrup 1970).[485] It is possible to calculate the maximum amount of a herbicide such as 2,4-D that might be applied to crop-

TABLE V–16—Maximum Levels of Herbicide Residues Found in Irrigation Water as a Result of Ditchbank Treatment[a]

Herbicide and canal treated	Treatment rate, lb/A	Water flow in cfs	Maximum concentration of residue, μg/l
DALAPON			
Five-mile Lateral	20	15	365[b]
Lateral No. 4	6.7	290	23
Manard Lateral	9.6	37	39
Yolo Lateral	10.5	26	162
TCA			
Lateral No. 4	3.8	290	12
Manard Lateral	5.4	37	20
Yolo Lateral	5.9	26	69
2,4-D AMINE SALT			
Lateral No. 4	1.9	290	5
Manard Lateral	2.7	37	13
Yolo Lateral	3.0	26	36

[a] Frank et al. (1970)[497].

[b] High level of residue probably due to atypical treatment.

land following its use on an irrigation bank. A four-mile-long body of irrigation water contaminated with 2,4-D and flowing at a velocity of one mile per hour, would be diverted onto an adjacent field for a period of 4 hours. A diversion rate of two acre inches of water in 10 hours would deliver 0.8 inch of contaminated water per acre. If this amount of water contained 50 μg/l of 2,4-D (a higher concentration than is usually observed), it would deposit slightly less than 0.009 lb of 2,4-D per acre of cropland. Levels of 2,4-D residues of greater magnitude have not caused injury to irrigated crops (see Table V-15).

The manner in which irrigation water containing herbicides is applied to croplands may influence the presence and amounts of residues in crops (Stanford Research Institute 1970).[500] For example, residues in leafy crops may be greater when sprinkler irrigated than when furrow irrigated, and the converse may be true with root crops.

If there is accidental contamination of field, forage, or vegetable crops by polluted irrigation water, the time interval between exposure and harvesting of the crop is important, especially with crops used for human consumption. Factors to be considered with those mentioned above include the intensity of the application, stage of growth, dilution, and pesticide degradability in order to assess the amount of pesticide that may reach the ultimate consumer (U. S. Department of Health, Education and Welfare 1969).[506] Pesticides applied to growing plants may affect the market quality by causing changes in the chemical composition, appearance, texture, and flavor of the product harvested for human consumption (NRC 1968).[501]

Recommendation

Pesticide residues in irrigation waters are variable depending upon land and crop management practices. Recent data indicate pesticide residues are declining in irrigation waters, with concentrations less than 1.0 μg/l being detected. To date
have been no documented toxic effects on
irrigated with waters containing insecticide
dues. Because of these factors and the ma
variability in crop sensitivity, no recommenda
is given for insecticide residues in irrigation wa
For selected herbicides in irrigation water,
recommended that levels at the crop not ex
the recommended maximum concentration l
in Table V–16.

PATHOGENS

Plant Pathogens

The availability of "high quality" irrigation water
lead to the reuse of runoff water or tailwater and s
quently lead to a serious but generally unrecognized
lem, that of the distribution of plant pathogenic orgar
such as bacteria, fungi, nematodes, and possibly vir
This is most serious when it occurs on previously nonfa
lands.

Distribution of Nematodes Wide distribution
plant-nematodes in irrigation waters of south central W
ington and the Columbia Basin of eastern Washington
demonstrated by Faulkner and Bolander (1966,[515] 197
When surface drainage from agricultural fields is colle
and reintroduced into irrigation systems; without first b
impounded in settling basins, large numbers of nemat
can be transferred. Faulkner and Bolander's data indic
that an acre of land in the Lower Yakima Valley may
ceive from 4 million to over 10 million plant-para
nematodes with each irrigation. Numbers of nemat
transported vary with the growing season, but some
were detectable in irrigation water and demonstrated t
infective were *Meloidogyne hapla*, *Heterodera schachtii*, *Prat*
chus sp., and *Tylenchorhynchus* sp.

Meagher (1967)[526] found that plant-parasitic nemat
such as the citrus nematode, *Tylenchulus semipenetrans*, r
be spread by subsoil drainage water reused for irrigati

Thomason and Van Gundy (1961)[530] showed anot
means by which nematodes may possibly enter irrigat
supplies. Two species of rootknot nematode, *Meloido*
incognita and *M. javanica*, were found reproducing on arr
weed, *Pluchea sericea*, at the edge of sandbars in the Color
River at Blythe, California. No conclusive evidence t
nematodes entered the river was presented, but infested
and infected roots were in direct contact with the water

Plant-parasitic nematodes are essentially aquatic anim
and may survive for days or weeks immersed in wat
Unless provisions are made for excluding them from
settling them out of irrigation water, they may seriou
deteriorate water quality in areas of the United States
pendent on irrigation for crop production.

Distribution of Fungi Surveys were conducted to
termine the origins and prevalence of *Phytophthora* sp.,

fungus pathogenic to citrus, in open irrigation canals and reservoirs in five southern California counties by Klotz et al. (1959).[523] *Phytophthora* progagules were detected by trapping them on healthy lemon fruits suspended in the water.

Of the 12 canals tested from September 1957 to September 1958, all yielded *Phytophthora* sp. at one time or another, some more consistently than others. *Phytophthora citrophthora* was the most common and was recovered from 11 canals.

In the five canals where it was possible to set the lemon traps at the source of the water, no *Phytophthora* sp. were recovered. However, as the canals passed through citrus areas where excess irrigation water or rain runoff could drain into the canals, the fungi were readily isolated. Soil samples collected from paths of runoff water that drained into irrigation canals yielded *P. citrophthora*, indicating that *Phytophthora* zoospores from infested citrus groves can be introduced into canals.

One of three reservoirs was found to be infested with *P. parasitica*. Application of copper sulfate effectively controlled the fungus under the static condition of the water in the reservoir. Chlorination (2 mg/l for 2 minutes) effectively killed the infective zoospores of *Phytophthora* sp. under laboratory conditions.

McIntosh (1966)[525] established that *Phytophthora cactorum*, which causes collar-rot of fruit trees in British Columbia, contaminates the water of many irrigation systems in the Okanagan and Similkamen Valleys. The fungus was isolated from 15 sources including ponds, reservoirs, rivers, creeks, and canals. It had been established previously that *P. cactorum* was widespread in irrigated orchard soils of the area, but could not be readily detected in non-irrigated soils.

Many plant-pathogenic fungi normally produce fruiting bodies that are widely disseminated by wind. A number do not, however, and these could easily be disseminated by irrigation water.

Distribution of Viruses Most plant pathogenic viruses do not remain infestive in the soil outside the host or vector. Two exceptions may be tobacco mosaic virus (TMV) and tobacco necrosis virus (TNV). There is some evidence that these persist in association with soil colloids and can gain entry to plant roots through wounds. Hewitt et al. (1958)[520] demonstrated that fan leaf virus of grape is transmitted by a dagger nematode, *Xiphinema index*. To date, three genera of nematodes, *Xiphinema*, *Longidorus*, and *Trichodorus* are known to transmit viruses. The first two of these genera transmit polyhedral viruses of the Arabis mosaic group. *Trichdorus* spp. transmit tubular viruses of the Tobacco Rattles group.

Infective viruses are known to persist in the nematode vector for months in the absence of a host plant. This information, coupled with Faulkner and Bolander's (1966,[515] 1970)[516] proof of the distribution of nematodes in irrigation water, suggested the possibility that certain plant viruses could be distributed in their nematode vectors in irrigation water. To date, no direct evidence for this has been published.

Several other soil-borne plant-pathogenic viruses are transmitted to hosts by soil fungi. The ability of the fungus *Olpidium brassicae* to carry and transmit Lettuce Big Vein Virus (LBVV) was recently demonstrated (Grogan et al. 1958,[519] Campbell 1962,[513] Teakle 1969[529]). It is carried within the zoospore into fresh roots and there released. The most likely vehicle for its distribution in irrigation water would be resting sporangia carried in runoff water from infested fields. The resting sporangia are released into the soil from decaying roots of host plants. Another economically important virus transmitted by a soil fungus is Wheat Mosaic Virus carried by the fungus *Polymyxa graminis* (Teakle 1969).[529]

Another means of spread of plant viruses (such as Tobacco Rattles Virus and Arabis Mosaic Viruses that are vectored by nematodes) is through virus-infected weed seed carried in irrigation water.

Distribution of Bacteria Bacterial plant pathogens would appear to be easily transported in irrigation water. However, relatively few data have been published concerning these pathogens. Kelman (1953)[522] reported the spread of the bacterial wilt organism of tobacco in drainage water from fields and in water from shallow wells. He also noted spread of the disease along an irrigation canal carrying water from a forested area, but no direct evidence of the bacterium in the water was presented. Local spread in runoff water is substantiated but not in major irrigation systems.

Controlling plant disease organisms in irrigation water should be preventive rather than an attempt to remove them once they are introduced. In assuring that irrigation water does not serve for the dispersal of important plant pathogens, efforts should be directed to those organisms that are not readily disseminated by wind, insects, or other means. Attention should be focused on those soil-borne nematodes, fungi, viruses, and bacteria that do not spread rapidly in nature.

Two major means of introduction of plant pathogens into irrigation systems are apparent. The most common is natural runoff from infested fields and orchards during heavy rainfall and floods. The other is collection of irrigation runoff or tailwater and its return to irrigation canals. If it is necessary to trap surface water, either from rainfall or irrigation drainage, provisions should be made to impound the water for sufficient time to allow settling out of nematodes and possibly other organisms.

Water may be assayed for plant pathogens, but there are thousands, or perhaps millions of harmless microorganisms for every one that causes a plant disease. However, plant pathogenic nematodes, and perhaps certain fungi, can be readily trapped from irrigation water, easily identified, and used as indicators of contamination (Klotz et al. 1959,[523] Faulkner and Bolander 1966,[515] McIntosh 1966[525]).

Plant infection is not considered serious unless an economically important percentage of the crop is affected. The real danger is that a trace of plant disease can be spread by water to an uninfected area, where it can then be spread by other means and become important. It is unlikely that any method of water examination would be as effective in preventing this as would the prohibitions such as those suggested above.

Human and Animal Pathogens

Many microorganisms, pathogenic for either animals or humans, or both, may be carried in irrigation water, particularly that derived from surface sources. The list comprises a large variety of bacteria, spirochetes, protozoa, helminths, and viruses which find their way into irrigation water from municipal and industrial wastes, including food-processing plants, slaughterhouses, poultry-processing operations, and feedlots. The diseases associated with these organisms include bacillary and amebic dysentery, *Salmonella* gastroenteritis, typhoid and paratyphoid fevers, leptospirosis, cholera, vibriosis, and infectious hepatitis. Other less common infections are tuberculosis, brucellosis, listeriosis, coccidiosis, swine erysipelas, ascariasis, cysticercosis and tapeworm disease, fascioliasis, and schistosomiasis.

Of the types of irrigation commonly practiced, sprinkling requires the best quality of water from a microbiological point of a view, as the water and organisms are frequently applied directly to that portion of the plant above the ground, especially fruits and leafy crops such as strawberries, lettuce, cabbage, alfalfa, and clover which may be consumed raw by humans or animals. Flooding the field may pose the same microbiological problems if the crop is eaten without thorough cooking. Subirrigation and furrow irrigation present fewer problems as the water rarely reaches the upper portions of the plant; and root crops, as well as normal leafy crops and fruits, ordinarily do not permit penetration of the plant by animal and human pathogens. Criteria for these latter types may also depend upon the characteristics of the soil, climate and other variables which affect survival of the microorganisms.

Benefits can be obtained by coordinating operation of reservoir releases with downstream inflows to provide sedimentation and dilution factors to markedly reduce the concentrations of pathogens in irrigation water (LeBosquet 1945,[524] Camp et al. 1949[512]).

The common liver fluke, *Fasciola hepatica*, the ova of which are spread from the feces of many animals, commonly affects cattle and sheep (Allison 1930,[510] U.S. Dept. Agriculture 1961[531]), and may affect man. The intermediate hosts, certain species of snails, live in springs, slow-moving swampy waters, and on the banks of ponds, streams, and irrigation ditches. After development in the snail, the cercarial forms emerge and encyst on grasses, plants, bark, or soil. Cattle and sheep become infected by ingestion of grasses, plants, or water in damp or irrigated pas where vegetation is infested with metacercariae. contracts the disease by ingesting plants such as water or lettuce containing the encysted metacercariae.

Ascaris ova are also spread from the feces of infected mals and man and are found in irrigation water (Wang Dunlop 1954).[532] Cattle and hogs are commonly infe where the adult worms mature in the intestinal tract, s times blocking the bile ducts. *Ascaris* ova have been ported to survive for 2 years in irrigated soil and have found on irrigated vegetables even when chlorinate fluent was used for irrigation (Gaertner and Mue 1951).[517]

Schistosomiasis, although not yet prevalent in the Un States except in immigrants from areas where the dis exists, should be considered because infected individ may move about the country and spread the disease. life cycle of these schistosomes is similar to that of the l fluke, in that eggs from the feces or urine of infected i viduals are spread from domestic wastes and may re surface irrigation water where the miracidial forms en certain snails and multiply, releasing cercariae. Althou these cercariae may produce disease if ingested by man, more common method of infection is through the skin individuals working in infested streams and irrigat ditches. Such infections are most common in Egypt (Barl 1937)[511] and other irrigated areas where workers wade in water without boots. It is unlikely that the cercariae wou survive long on plants after harvest.

Little is known of the possibility that enteric viruses su as polioviruses, Coxsackie, ECHO, and infectious hepati viruses may be spread through irrigation practices. Murp and his co-workers (Murphy et al. 1958)[527] tested the su vival of polioviruses in the root environment of tomato a pea plants in modified hydroponic culture. In a seco paper, Murphy and Syverton (1958)[528] studied the recove and distribution of a variety of viruses in growing plan The authors conclude that it is unlikely that plants or pla fruits serve as reservoirs and carriers of poliovirus. Ho ever, their findings of significant absorption of a mammalia virus in the roots of the plants suggest that more research needed in this area.

Many microorganisms other than those specifically men tioned in this section may be transmitted to plants, animal and humans through irrigation practices. One of the mor serious of these is vibriosis. In some cases, definitive infor mation on microorganisms is lacking. Although others, suc as the cholera organisms, are significant in other parts the world, they are no longer important in the Unite States.

Direct search for the presence of pathogenic microorganisms in streams, reservoirs, irrigation water, or on irrigated plants is too slow and cumbersome for routine control or assessment of quality. Instead, accepted index organisms such as the coliform group and fecal coli (Kabler et al. 1964),[521] which are usually far more numerous from these sources, and other biological or chemical tests, are used to assess water quality.

Recent studies have emphasized the value of the fecal coliform in assessing the occurrence of salmonella, the most common bacterial pathogen in irrigation water. Geldreich and Bordner (1971)[515] reviewed field studies involving irrigation water, field crops, and soils, and stated that when the fecal coliform density per 100 ml was above 1,000 organisms in various stream waters, *Salmonella* occurrence reached a frequency of 96.4 per cent. Below 1,000 fecal coliforms per 100 ml (range 1–1000) the occurence of *Salmonella* was 53.5 per cent.

Further support for the limit of 1,000 fecal coliforms per 100 ml of water is shown in the recent studies of Cheng et al. (1971),[514] who reported that as the fecal coliforms density reached less than 810 per 100 ml. downstream from a sewage treatment plant, *Salmonella* were not recovered.

Recommendation

Irrigation waters below the fecal coliform density of 1,000/100 ml should contain sufficiently low concentrations of pathogenic microorganisms that no hazards to animals or man result from their use or from consumption of raw crops irrigated with such waters.

THE USE OF WASTEWATER FOR IRRIGATION

An expanding population requires new sources of water for irrigation of crops and development of disposal systems for municipal and other wastewaters that will not result in the contamination of streams, lakes, and oceans. Irrigation of crops with wastewater will probably be widely practiced because it meets both needs simultaneously.

Wastewater From Municipal Treatment Systems

Various human and animal pathogens carried in municipal wastewater need to be nullified. Pathogens carried in municipal wastewater include various bacteria, spirochetes, helminths, protozoa, and viruses (Dunlop 1968).[538] Tanner (1944)[555] and Rudolfs et al. (1950)[555] have reviewed the literature on the occurrence and survival of pathogenic and nonpathogenic enteric bacteria in soil, water, sewage, and sludges, and on vegetation irrigated or fertilized with these materials. It would appear from these reviews that fruits and vegetables growing in infected soil can become contaminated with pathogenic bacteria and that these bacteria may survive for periods of a few days to several weeks or more in the soil, depending upon local conditions, weather, and the degree of contamination. However, Geldreich and Bordner (1971)[541] noted that pathogens are seldom detected on farm produce unless the plant samples are grossly contaminated with sewage or are observed to have fecal particles clinging to them. The level of pathogen recovery depends upon the incidence of waterborne disease in the area, the soil type, soil pH, soil moisture content, soil nutrient levels, antagonistic effects of other organisms, temperature, humidity, and length of exposure to sunlight.

Norman and Kabler (1953)[551] made coliform and other bacterial counts in samples of sewage-contamination river and ditch waters and of soil and vegetable samples in the fields to which these waters were applied. They found that although the bacterial contents of both river and ditch waters were very high, both soil and vegetable washings had much lower counts. For example, where irrigation water had coliform counts of 230,000/100 ml, leafy vegetables had counts of 39,000/100 grams and smooth vegetables, such as tomatoes and peppers, only 1,000/100 grams. High enterococcus counts accompanied high coliform counts in water samples, but enterococcus counts did not appear to be correlated in any way with coliform counts in soil and vegetable washings.

Dunlop and Wang (1961)[539] have also endeavored to study the problem under actual field conditions in Colorado. *Salmonella*, *Ascaris* ova, and *Entamoeba coli* cysts were recovered from more than 50 per cent of irrigation water samples contaminated with either raw sewage or primary-treated, chlorinated effluents. Only one of 97 samples of vegetables irrigated with this water yielded *Salmonella*, but *Ascaris* ova were recovered from two of 34 of the vegetable samples. Although cysts of the human pathogen, *Entamoeba histolytica*, were not recovered in this work, probably due to a low carrier rate in Colorado: their similar resistance to the environment would suggest that these organisms would also survive in irrigation water for a considerable period of time. It should be pointed out, however, that this work was done entirely with furrow irrigation on a sandy soil in a semiarid region, and the low recoveries from vegetables cannot necessarily be applied to other regions or to sprinkler irrigation of similar crops. In fact, Muller (1957)[550] has reported that two places near Hamburg, Germany, where sprinkler irrigation was used, *Salmonella* organisms were isolated 40 days after sprinkling on soil and on potatoes, 10 days on carrots, and 5 days on cabbage and gooseberries.

Muller (1955)[549] has also reported that 69 of 204 grass samples receiving raw sewage by sprinkling were positive for organisms of the typhoid-paratyphoid group (*Salmonella*). The bacteria began to die off 3 weeks after sewage application; but 6 weeks after application, 5 per cent of the samples were still infected. These findings emphasize the importance of having good quality water for sprinkler irrigation.

Tubercle bacilli have apparently not been looked for on irrigated crops in the United States. However, Sepp (1963)[557] stated that several investigations on tuberculosis infection of cattle pasturing on sewage-irrigated land have been carried out in Germany. The investigators are in general agreement that if sewage application is stopped 14 days before pasturing, there is no danger that the cattle will con-tract bovine tuberculosis through grazing. In contrast, Dedie (1955)[537] reported that these organisms can remain infective for 3 months in waste waters and up to 6 months in soil. The recent findings of a typical mycobacteria in intestinal lesions of cattle with concurrent tuberculin sensitivity in the United States may possibly be due to ingestion of these organisms either from soil or irrigated pastures.

Both animals and human beings are subject to helminth infections—ascariasis, fascioliasis, cysticerosis and tapeworm infection, and schistosomiasis—all of which may be transmitted through surface irrigation water and plants infected with the ova or intermediate forms of the organisms. The ova and parasitic worms are quite resistant to sewage treatment processes as well as to chlorination (Borts 1949)[533] and have been studied quite extensively in the application of sewage and irrigation water to various crops (Otter 1951,[553] Selitrennikova and Shakhurina 1953,[556] Wang and Dunlop 1954[560]). Epidemics have been traced to crop contamination with raw sewage but not to irrigation with treated effluents (Dunlop 1968).[538]

The chances of contamination of crops can be further reduced by using furrow or subirrigation instead of sprinklers, by stopping irrigation as long as possible before harvest begins, and by educating farm workers on sanitation practices for harvest (Geldreich and Bordner 1971).[541] It is better to restrict irrigation with sewage water to crops that are adequately processed before sale and to crops that are not used for human consumption.

Standards are needed to establish the point where irrigation waters that contain some sewage water must be restricted and to indicate the level to which wastewater must be treated before it can be used for unrestricted irrigation.

The direct isolation of pathogens is too slow and complicated for routine analyses of water quality (Geldreich and Bordner 1971).[541] A quantitative method for *Salmonella* detection has been developed recently (Cheng et al. 1971).[536] However, the minimum number of *Salmonella* required to cause infection are not known, and data are not available to correlate incidence of *Salmonella* with the incidence of other pathogens (Geldreich 1970).[540] The fecal coliform group has a high positive correlation with fecal contamination from warm-blooded animals and should be used as an indicator of pollution until more direct methods can be developed.

Information is available indicating the levels of fecal coliform at which pathogens can no longer be isolated from irrigation water. *Salmonella* were consistently recovered in the Red River of the north when fecal coliform levels were 1000/100 ml or higher, but were not detected at fecal coliform levels of 218 and 49/100 ml (ORSANCO Water Users Committee 1971).[552] Cheng et al. (1971)[536] reported numbers of fecal coliform at various distances downstream, and *Salmonella* was not isolated from samples containing less than 810 fecal coliforms/100 ml. Geldreich and Bordner (1971)[541] presented data from nationwide field investigations showing the relationship between *Salmonell*
currence and fecal coliform densities. *Salmonella*
rence was 53.5 per cent for streams with less than 1,00
coliforms per 100 ml and 96.4 per cent for streams
more than 1,000 fecal coliforms per 100 ml. A max
level of 1,000 fecal coliforms per 100 ml of water ap
to be a realistic standard for water used for unrestrict
rigation.

Secondary sewage effluent can be chlorinated to r
the fecal coliform bacteria below the 1,000 per ml limi
viruses may survive chlorination. Wastewater used fo
restricted irrigation should receive at least primary
biological secondary treatment before chlorination. F
tion through soil is another effective way to remove
bacteria (Merrell et al. 1967,[548] Bouwer 1968,[534] Bo
and Lance 1970,[535] Lance and Whisler 1972).[544]

The elimination of health hazards has been the pri
consideration regulating the use of sewage water i
past. But control of nutrient loads must also be a prime
cern. The nutrients applied to the land must be bala
against the nutrient removal capacity of the soil-plant
tem to minimize groundwater contamination. Ka
(1968)[542] reported that various crops removed only 2
60 per cent of the phosphorus applied in sewage water,
the total removal by the soil-plant system was about 99
cent.

Many biological reactions account for nitrogen rem
from wastewater, but heavy applications of sewage w
can result in the movement of nitrogen below the root z
(Lance[543] *in press* 1972).

Work with a high-rate groundwater recharge system
lizing sewage water resulted in 30 per cent nitrogen rem
from the sewage water (Lance and Whisler 1972).[544]

Nitrate can accumulate in plants supplied with nitro
in excess of their needs to the point that they are a haz
to livestock. Nitrate usually accumulates in stems and le
rather than in seeds (Viets 1965).[559]

The concentration of trace elements in sewage water u
for irrigation should meet the general requirements est
lished for other irrigation waters. Damage to plants by t
elements has not yet been a problem on lands irrigated w
sewage water in the United States. Problems could deve
in some areas, however, if industries release potentially to
elements such as zinc or copper into sewage treatment s
tems in large quantities. The concentration of boron
sewage water may become a problem if the use of this e
ment in detergents continues to increase. The guidelines
salinity in irrigation water also apply to sewage water us
for irrigation.

The organic matter content of secondary sewage wa
does not appear to be a problem limiting its use in irrigatio
Secondary sewage effluent has been infiltrated into riv
sand at a rate of 100 meters per year in Arizona (Bouw
and Lance 1970).[535] The COD of this water was consistent
reduced from 50 mg/l to 17 mg/l or the same COD as t

native groundwater of the area. The organic load might be a factor in causing clogging of soils used for maximum irrigation to promote groundwater recharge. Suspended solids have not been reported to be a problem during irrigation with treated effluents.

Wastewater From Food Processing Plants and Animal Waste Disposal Systems

Wastewater from food processing plants, dairy plants, and lagoons used for treatment of wastes from feedlots, poultry houses, and swine operations, may also be used for irrigation. Some food processing wastewater is high in salt content and the guidelines for salinity control concerning unrestricted irrigation in the Section, Irrigation Quality for Arid Regions, should be followed (Pearson *in press* 1972[554]). Effluents from plants using a lye-peeling process are generally unsuitable for irrigation due to their high sodium content. All of the wastewaters mentioned above are usually much higher in organic content than secondary sewage effluent. This can result in clogging of the soil surface, if application rates are excessive (Lawton et al. 1960,[547] Law 1968,[545] Law et al. 1970).[546] Only well drained soils should be irrigated, and runoff should be prevented unless a closely managed spray-runoff treatment system is used. The nutrient content of the wastewaters varies considerably. The nutrient load applied should be balanced against the nutrient removal capacity of the soil. Food processing wastes present no pathogenic problem and may be used for unrestricted irrigation. Since some animal pathogens also infect humans, water containing animal wastes should not be applied with sprinkler systems to crops that are consumed raw.

Recommendations

- **Raw sewage should not be used in the United States for irrigation or land disposal.**
- **Sewage water that has received primary treatment may be used on crops not used for human consumption. Primary effluents should be free of phytotoxic materials.**
- **Sewage water that has received secondary treatment may also be used to irrigate crops that are canned or similarly processed before sale.**
- **Fecal coliform standard for unrestricted irrigation water should be a maximum of 1,000/100 ml.**
- **The amount of wastewater that can be applied is determined by balancing the nutrient load of the wastewater against the nutrient removal capacity of the soil.**
- **Phosphorus will probably not limit sewage application because of the tremendous adsorption capacity of the soil.**
- **The nitrogen load should be balanced against crop removal within 30 per cent unless additional removal can be demonstrated.**

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UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

OFFICE OF
SOLID WASTE AND EMERGENCY
RESPONSE

December 5, 2003

OSWER Directive 9285.7-53

MEMORANDUM

SUBJECT: Human Health Toxicity Values in Superfund Risk Assessments

FROM: Michael B. Cook, Director /s/
Office of Superfund Remediation and Technology Innovation

TO: Superfund National Policy Managers, Regions 1 - 10

Purpose

This memorandum revises the hierarchy of human health toxicity values generally recommended for use in risk assessments, originally presented in Risk Assessment Guidance for Superfund Volume I, Part A, Human Health Evaluation Manual (RAGS) (OSWER 9285.7-02B, EPA/540/1-89/009, December 1989).
(http://www.epa.gov/superfund/programs/risk/ragsa/index.htm)

It updates the hierarchy of human health toxicity values and provides guidance for the sources of toxicity information that should generally be used in performing human health risk assessments at Comprehensive Environmental Response Compensation and Liability Act (CERCLA or "Superfund") sites. It does not address the situation where new toxicity information is brought to the attention of the U.S. Environmental Protection Agency (EPA). It also does not provide guidance or address toxicity or reference values for ecological risk.

This memorandum presents current Office of Solid Waste and Emergency Response (OSWER) technical and policy recommendations regarding human health toxicity values in risk assessments. EPA and state personnel may use and accept other technically sound approaches, either on their own initiative, or at the suggestion of potentially responsible parties, or other interested parties. Therefore, interested parties are free to raise questions and objections about the substance of this memorandum and the appropriateness of the application of this document to a particular situation. EPA will, and States should, consider whether the recommendations or interpretations in this memorandum are appropriate in that situation. This memorandum does not impose any requirements or obligations on EPA, States, or other federal agencies, or the regulated community. The sources of authority and requirements in this matter are the relevant statutes and regulations (e.g., CERCLA, Resource Conservation and Recovery Act). EPA welcomes public comments on this memorandum at any time and may consider such comments in future revisions of this memorandum.

Background

Superfund risk assessments are performed for a number of reasons, including to evaluate whether action is warranted under CERCLA, to establish protective cleanup levels, and to determine the residual risk posed by response actions. Generally, toxicity assessment is an integral part of risk assessment. Volume I, Part A of RAGS provides guidance on how to conduct the human health portion of the risk assessment. Chapter 7.4.1 presents a hierarchy of human health toxicity values for use in risk assessments at Superfund sites. The hierarchy presented in RAGS Part A is being updated to reflect that additional sources of peer reviewed values have become available since 1989. In addition, the EPA Health Effects Assessment Summary Tables (HEAST) document, which was identified as the second tier of data, has not been updated since 1997. As a result, HEAST may not provide the most current source of information on some contaminants.

This revised hierarchy recognizes that EPA should use the best science available on which to base risk assessments. In general, if health assessment information is available in the Integrated Risk Information System ["IRIS," http://www.epa.gov/iris/] for the contaminant under evaluation, risk assessors normally need not search further for additional sources of information. Since EPA's development and use of peer review in toxicity assessments, IRIS assessments have undergone external peer review in accordance with Agency peer review guidance at the time of the assessment. IRIS health assessments contain Agency consensus toxicity values. If such information is not available in IRIS, risk assessors should consider other sources of available data based on the hierarchy presented in this memorandum.

EPA recognizes that there may be other sources of toxicological information. As noted in the December 1993 memorandum entitled "Use of IRIS Values in Superfund Risk Assessment" (OSWER Directive 9285.7-16, December 21, 1993):

> "...IRIS is not the only source of toxicology information, and in some cases more recent, credible and relevant data may come to the Agency's attention. In particular, toxicological information other than that in IRIS may be brought to the Agency by outside parties. Such information should be considered along with the data in IRIS in selecting toxicological values; ultimately, the Agency should evaluate risk based upon its best scientific judgement and consider all credible and relevant information available to it."

This memorandum is intended to help regional risk assessors identify appropriate sources of toxicological information as a means of streamlining decisions. It does not specifically address the situation where additional scientific information is brought to the attention of EPA. In those cases, EPA risk assessors and decision makers should consider the information as appropriate on a case by case basis.

Revised Recommended Human Health Toxicity Value Hierarchy

This memorandum revises the recommended hierarchy of toxicological sources of information which Regional risk assessors and managers should initially consider for site-specific risk assessments. The revised recommended toxicity value hierarchy is as follows:

Tier 1- EPA's IRIS

Tier 2- EPA's Provisional Peer Reviewed Toxicity Values (PPRTVs) – The Office of Research and Development/National Center for Environmental Assessment/Superfund Health Risk Technical Support Center (STSC) develops PPRTVs on a chemical specific basis when requested by EPA's Superfund program.

Tier 3- Other Toxicity Values – Tier 3 includes additional EPA and non-EPA sources of toxicity information. Priority should be given to those sources of information that are the most current, the basis for which is transparent and publicly available, and which have been peer reviewed.

IRIS remains in the first tier of the recommended hierarchy as the generally preferred source of human health toxicity values. IRIS generally contains reference doses (RfDs), reference concentrations (RfCs), cancer slope factors, drinking water unit risk values, and inhalation unit risk values that have gone through a peer review and EPA consensus review process. IRIS normally represents the official Agency scientific position regarding the toxicity of the chemicals based on the data available at the time of the review.

The second tier is EPA's PPRTVs. Generally, PPRTVs are derived for one of two reasons. First, the STSC is conducting a batch wise review of the toxicity values in HEAST (now a Tier 3 source). As such reviews are completed, those toxicity values will be removed from HEAST, and any new toxicity value developed in such a review will be a PPRTV and placed in the PPRTV database. Second, Regional Superfund Offices may request a PPRTV for contaminants lacking a relevant IRIS value. The STSC uses the same methodologies to derive PPRTVs for both.

The third tier includes other sources of information. Priority should be given to sources that provide toxicity information based on similar methods and procedures as those used for Tier I and Tier II, contain values which are peer reviewed, are available to the public, and are transparent about the methods and processes used to develop the values. Consultation with the STSC or headquarters program office is recommended regarding the use of the Tier 3 values for Superfund response decisions when the contaminant appears to be a risk driver for the site. In general, draft toxicity assessments are not appropriate for use until they have been through peer review, the peer review comments have been addressed in a revised draft, and the revised draft is publicly available.

Additional sources may be identified for Tier 3. Toxicity values that fall within the third tier in the hierarchy include, but need not be limited to, the following sources.

- The California Environmental Protection Agency (Cal EPA) toxicity values are peer reviewed and address both cancer and non-cancer effects. Cal EPA toxicity values are available on the Cal EPA internet website at http://www.oehha.ca.gov/risk/chemicalDB//index.asp.

- The Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels (MRLs) are estimates of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse non-cancer health effects over a specified duration of exposure. The ATSDR MRLs are peer reviewed and are available at http://www.atsdr.cdc.gov/mrls.html on the ATSDR website.

- HEAST toxicity values are Tier 3 values. As noted above, the STSC is conducting a batch wise review of HEAST toxicity values. The toxicity values remaining in HEAST are considered Tier 3 values. The radionuclides HEAST toxicity values are available at http://www.epa.gov/radiation/heast/. The HEAST values on chemical contaminants are not currently available on an EPA internet site. They may be obtained by contacting a Superfund risk assessor.

Neither IRIS nor the PPRTV database contains radionuclide slope factors. Because EPA's Office of Radiation and Indoor Air (ORIA) obtains peer review on the radionuclide slope factors contained in Table 4 of HEAST (which are available on EPA/ORIA's internet website at http://www.epa.gov/radiation/heast/download.htm), routine consultation with STSC is generally not necessary on these values even when they may be a risk driver on a Superfund site. These radionuclide slope factors have been adopted by EPA in its Preliminary Remediation Goals for Radionuclide Calculator and are available on EPA's internet website at: http://epa-prgs.ornl.gov/radionuclides/ and the Soil Screening Guidance for Radionuclide documents, which are available at: http://www.epa.gov/superfund/resources/radiation/radssg.

Implementation

This memorandum provides a revised recommended hierarchy of human health toxicity values for Superfund sites and represents a revision of Chapter 7 of RAGS, Volume I, Part A. Superfund risk assessors should look to this hierarchy when evaluating risk for CERCLA response actions. Additional sources of toxicity values, which are not specifically referenced in this recommended hierarchy, can be considered.

Additional Information

Questions regarding this guidance or its use and implementation on a particular site should be directed to an EPA Regional Superfund risk assessor or toxicologist. Questions of a more general nature relating to this guidance should be directed to Mr. Dave Crawford of my staff at (703) 603- 8891, Crawford.Dave@epa.gov.

cc: Nancy Riveland, Superfund Lead Region Coordinator, USEPA Region 9
NARPM Co-Chairs
Joanna Gibson, OSRTI Documents Coordinator
OSRTI Center Directors and Senior Process Managers
Jim Woolford, FFRRO
Debbie Dietrich, OEPPR
Robert Springer, OSW
Cliff Rothenstein, OUST
Linda Garczynski, OBCR
Sandra Connors, FFEO
Susan Bromm, OSRE
Peter Preuss, NCEA
Charles Openchowski, OGC
John Michaud, OGC
David Kling, FFEO
Stephen Luftig, Senior Advisor to OSWER Assistant Administrator

STATE OF ILLINOIS)
)
COUNTY OF SANGAMON)

PROOF OF SERVICE

I, the undersigned, on oath state that I have served the attached Motion to Correct the Transcript, Errata Sheet Number 3, and Supplemental Testimony of the Illinois EPA upon the persons to whom it is directed, by placing a copy in an envelope addressed to:

Dorothy Gunn, Clerk
Illinois Pollution Control Board
James R. Thompson Center
100 W. Randolph St., Suite 11-500
Chicago, Illinois 60601
(FEDERAL EXPRESS)

Bill Richardson, Chief Counsel
Illinois Department of Natural Resources
One Natural Resources Way
Springfield, Illinois 62702-1271
(FIRST CLASS MAIL)

(Service List-FIRST CLASS MAIL)

Matthew Dunn, Esq.
Environmental Bureau Chief
Office of the Attorney General
James R. Thompson Center
100 W. Randolph St., 12th Floor
Chicago, Illinois 60601
(FIRST CLASS MAIL)

Richard McGill
Illinois Pollution Control Board
James R. Thompson Center
100 W. Randolph St., Suite 11-500
Chicago, Illinois 60601
(FEDERAL EXPRESS)

and mailing it from Springfield, Illinois on July 10, 2008 with sufficient postage affixed.

Kimberly A Geving

SUBSCRIBED AND SWORN TO BEFORE ME

This 10th day of July, 2008.

Brenda Boehner
Notary Public

BRENDA BOEHNER
MY COMMISSION EXPIRES 11-3-2009

Party Name	Role	City & State	Phone/Fax
IEPA Petitioner Kimberly A.Geving, Assistant Counsel	1021 North Grand Avenue East P.O. Box 19276	Springfield IL 62794-9276	217/782-5544 217/782-9807
Hodge Dwyer Zeman Interested Party Katherine D. Hodge Monica T. Rios	3150 Roland Avenue Post Office Box 5776	Springfield IL 62705-5776	217/523-4900 217/523-4948
Illinois Environmental Regulatory Group Interested Party Alec M. Davis	215 East Adams Street	Springfield IL 62701	217/522-5512 217/522-5518
Illinois Pollution Control Board Interested Party Richard McGill, Hearing Officer	100 W. Randolph St. Suite 11-500	Chicago IL 60601	312/814-3620 312/814-3669
Illinois Department of Natural Resources Interested Party William Richardson, Chief Legal Counsel	One Natural Resources Way	Springfield IL 62702-1271	217/782-1809 217/524-9640
Environmental Law & Policy Center Interested Party Albert Ettinger, Senior Staff Attorney	35 E. Wacker Suite 1300	Chicago IL 60601	312 795 3707
Office of the Attorney General Interested Party Matt Dunn, Environmental Bureau Chief	James R. Thompson Center 100 W. Randolph, 12th Floor	Chicago IL 60601	

Total number of participants: 8