Using Disinfected Tertiary Recycled Water for Non-Dairy Livestock Watering: A Human and Animal Health Evaluation for the State of California

INDEPENDENT ADVISORY PANEL FINAL REPORT

Prepared by:

NWRI Independent Advisory Panel for the California State Water Resources Control Board

Robert Poppenga, Nicholas Ashbolt, Andrea Mikolon, Brian Pecson,
Channah Rock, and David J. Smith

Prepared for:

State Water Resources Control Board

Division of Drinking Water

Sacramento, California USA

Submitted by:

National Water Research Institute

Fountain Valley, California USA

www.nwri-usa.org

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For more information, please contact:

National Water Research Institute
18700 Ward Street
Fountain Valley, California 92708 USA
Phone: (714) 378-3278
Fax: (714) 378-3375
www.nwri-usa.org

Kevin M. Hardy, J.D., Executive Director
Suzanne Sharkey, Water Resources Scientist and Project Manager

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September 30, 2018

Randy Barnard, PE, Recycled Water Unit Chief
Recycled Water Unit, Division of Drinking Water
State Water Resources Control Board
1350 Front Street, Room 2050
San Diego, CA 92101

Dear Mr. Barnard:

The National Water Research Institute (NWRI) is pleased to submit this report on **Using Disinfected Tertiary Recycled Water for Non-Dairy Livestock Watering: A Human and Animal Health Evaluation for the State of California.** This report was prepared for the State Water Board by an NWRI Independent Advisory Panel that studied whether the use of disinfected tertiary recycled water (DTRW) to water commercial, non-dairy livestock, would pose a significant risk to the public or livestock health. Note that DTRW is defined by Section 60301.230 of Title 22 of the California Code of Regulations.

This report presents a consensus by the six-member Panel, which represented expertise in veterinary medicine and clinical toxicology, animal physiology and metabolism, veterinary epidemiology, engineered water treatment processes and technologies, water quality and public health, microbiology, and risk assessment.

The Panel concluded that the health outcomes of using recycled water for non-dairy livestock watering are not well-understood because of critical data gaps for pathogens and chemicals of concern in recycled water and the potential impact on livestock. Therefore, based on the existing data, the Panel could not determine that the use of DTRW for livestock watering would be uniformly protective of public health and the health of livestock or people who eat animal food products, such as meat and eggs, from livestock.

The Panel, therefore, recommends several best management practices (BMPs) to assist DDW with developing additional water recycling criteria to make DTRW safe for livestock watering. The BMPs include: source control that complies with the National Pretreatment Program and excludes concentrated animal pathogens and industrial chemicals from the sewershed; UV disinfection; a chlorine residual in the distribution system; and coordination with appropriate state agencies. As a supplement to current DTRW standards, these BMPs will provide a suitable and safe water source for non-dairy livestock.

The Panel hopes that the findings and recommendations of this report will help the State Water Board and communities throughout California ensure the safety of recycled water for non-dairy livestock watering.

On behalf of the Panel, NWRI would like to thank the State Water Board for supporting this work, including the time, information, and resources that allowed the Panel to meet dozens of times, to conduct research, and to prepare and edit this report.

Sincerely,

NATIONAL WATER RESEARCH INSTITUTE

Kevin M. Hardy, JD
Executive Director

On behalf of the Independent Advisory Panel:

- Chair: Robert Poppenga, DVM, PhD, DABVT, California Animal Health and Food Safety Laboratory, School of Veterinary Medicine, University of California
- Nicholas Ashbolt, PhD, School of Public Health, University of Alberta
- Andrea Mikolon, DVM, MPVM, PhD, Animal Health Branch, California Department of Food and Agriculture
- Brian Pecson, PhD, PE, Trussell Technologies, Inc.
- Channah Rock, PhD, University of Arizona
- David J. Smith, PhD, Animal Metabolism-Agricultural Chemicals Research, United States Department of Agriculture, Agricultural Research Service

National Water Research Institute
18700 Ward Street, Fountain Valley, CA 92708
(714) 378-3278 • Fax: (714) 378-3375
www.NWRI-USA.org

Kevin M. Hardy
Executive Director
khardy@NWRI-USA.org

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This report is the consensus of an Independent Advisory Panel (Panel) administered by the National Water Research Institute (NWRI), a Joint Powers Agency and 501c3 nonprofit corporation based in Southern California. The Independent Advisory Panel is pleased to acknowledge the organizations and people whose support, assistance, and resources made this report possible.

Independent Advisory Panel

Panel Chair:

- Robert Poppenga, DVM, PhD, DABVT, California Animal Health and Food Safety Laboratory, School of Veterinary Medicine, University of California

Panel Members:

- Nicholas Ashbolt, PhD, University of Alberta
- Andrea Mikolon, DVM, MPVM, PhD, California Department of Food and Agriculture
- Brian Pecson, PhD, PE, Trussell Technologies, Inc.
- Channah Rock, PhD, University of Arizona
- David J. Smith, PhD, United States Department of Agriculture

State Water Resources Control Board

The Panel was formed by NWRI at the request of the Division of Drinking Water (DDW) of the California State Water Resources Control Board (State Water Board) under State Water Board Agreement No. 15-099-400. The Panel would like to thank the staff of the State Water Board, particularly Randy Barnard, for the information, materials, and suggestions provided during this Panel process.

National Water Research Institute

The Panel expresses its sincere appreciation for the NWRI staff who facilitated the Panel review process, organized Panel meetings, and produced this report, as well as all of the additional documentation that they provided to support the Panel's review process. The Panel recognizes the following NWRI staff:

- Kevin M. Hardy for facilitating the Panel process and report development.
- Mary Collins, Suzanne Sharkey, and Gina Vartanian for report development and editing.
- Brandi Caskey, Eileen Chao, and Dawna Hernandez for administrative support.

Peer Reviewers

The Panel thanks the following people for reviewing the report. Their insightful comments provided clarity for revisions and informed the Panel's final recommendations.

- E. Robert Atwill, DVM, MPVM, PhD, University of California, Davis
- James Crook, PhD, PE, Independent Environmental Consultant
- Charles Gerba, PhD, University of Arizona
- Jeffrey J. Mosher, Carollo Engineers, Inc.
- Randall Singer, DVM, PhD, University of Minnesota
- George Tchobanoglous, PhD, PE, University of California, Davis (Emeritus)

CONTENTS

FIGURES

TABLES

T a b l e s

ACRONYMS

ADI	Acceptable daily intake
ADME	Absorption, distribution, metabolism, and elimination
AMR	Antimicrobial resistance
ARG	Antibiotic-resistant gene
ATSDR	Agency for Toxic Substances and Disease Registry
BDOC	Biodegradable dissolved organic carbon
BFR	Brominated flame retardant
BMD	Benchmark dose
BMP	Best management practice
BOD	Biochemical oxygen demand
BOD_5	Biochemical oxygen demand over five days
BPA	Bisphenol A
BW	Body weight
CAFO	Concentrated animal feeding operation; a feedlot
CDC	Centers for Disease Control and Prevention
CCL	Contaminant Candidate List
CCL 3	Contaminant Candidate List 3
CCL 4	Contaminant Candidate List 4
CCME	Canadian Council of Ministers of the Environment
CCR	California Code of Regulations
CDFA	California Department of Food and Agriculture
CDPH	California Department of Public Health
CDPHE	Colorado Department of Public Health and Environment
$CDWG_L$	Canadian Drinking Water Guideline for Livestock
CEC	Chemical of emerging concern
cPAD	Chronic population adjusted dose

CT	The product of total chlorine residual (in milligrams per liter) and modal contact time (in minutes) measured at the same point
DDT	Dichlorodiphenyl trichloroethane
DDW	Division of Drinking Water of the California State Water Resources Control Board
DPR	Direct potable reuse
DS2.2	Disinfected secondary 2.2 recycled water
DS23	Disinfected secondary 23 recycled water
DTRW	Disinfected tertiary recycled water
DWC	Drinking Water Consumption
DWEL	Drinking water equivalent level
DWG	Australian Drinking Water Guidelines (2008)
EC	European Commission
EDC	Endocrine disrupting chemical
EEQ	Estrogenic equivalent
EFSA	European Food Safety Authority
EPA	US Environmental Protection Agency
EU	European Union
FDA	US Food and Drug Administration
FDA CVM	US Food and Drug Administration Center for Veterinary Medicine
FFDCA	Federal Food, Drug, and Cosmetic Act
FSIS	Food Safety and Inspection Service of the US Department of Agriculture
GAMA	Groundwater Ambient Monitoring and Assessment Program
GMF	Granular media filtration
HRT	Hydraulic residence time
HACCP	Hazard Analysis and Critical Control Point
IPR	Indirect potable reuse
LD_{50}	Lethal dose, 50 percent
LOAEL	Lowest Observed Adverse Effect Level

LRV	Log_{10} reduction value
MCL	Maximum Contaminant Level
MDR	Multidrug resistance
MEC	Measured environmental concentration
MF	Microfiltration
MLA	Minimum level of applicability
MLE	Modified Ludzack-Ettinger
MPN	Most Probable Number
MTL	Monitoring trigger level *(see Chapter 3)*
MTL	Maximum daily tolerable level *(see Appendix 5A)*
NARMS	National Antimicrobial Resistance Monitoring System
NF	Nanofiltration
NHANES	National Health and Nutrition Examination Survey
NOAEL	No Observable Adverse Effect Level
NOEL	No Observable Effect Level
NPDWR	National Primary Drinking Water Regulation
NTM	Non-tuberculosis mycobacteria
NWRI	National Water Research Institute
OK DEQ	Oklahoma Department of Environmental Quality
ORV	Oxidation-reduction potential
OPP	Office of Pesticide Programs
PCP	Polychlorinated phenol
PCR	Polymerase chain reaction
PDWC	Percentage drinking water concentration
PEC	Predicted environmental concentration
PFAS	Perfluoroalkylated compounds
PFOA	Perfluorooctanoic acid
PFOS	Perfluorooctane sulfonate

PGV	Provisional Guidelines Values
PHG	Public health goal
PNEC	Predicted no effect concentration
POM	Point of monitoring
POP	Persistent organic pollutant
PR	Pathogen reduction
PSR	Produce safety rule
RA	Regulatory action
RD	Regulatory determination
RfD	Reference dose
RO	Reverse osmosis
RRVL	Residue Repeat Violator List
RSC	Relative Source Concentration
SAP	Science Advisory Panel of the State Water Resources Control Board
SDWA	Safe Drinking Water Act
SFPUC	San Francisco Public Utilities Commission
SRT	Solids retention time
SS	Suspended solids
SWA	Surface water augmentation
SWRCB	State Water Resources Control Board (State Water Board)
TB	Tuberculosis
TCEP	Tris(2-carboxyethyl) phosphate
TDI	Tolerable daily intake
TDS	Total dissolved solids
TEQ	Toxic equivalency quotient
TOC	Total organic carbon
TSS	Total suspended solids
UF	Ultrafiltration

USDA	US Department of Agriculture
UV	Ultraviolet light
UVA	Ultraviolet light absorbance
WHO	World Health Organization
WQCC	Water Quality Control Commission of the Colorado Department of Public Health and Environment
WRCA	WateReuse California
WWTP	Wastewater treatment plant

TERMINOLOGY

Acute: Acute illnesses generally develop suddenly and last a short time, often only a few days or weeks.

Adulteration: Mixing other matter of an inferior and sometimes harmful quality with food or drink intended to be sold. As a result of adulteration, food or drink becomes impure and unfit for human consumption.

Acceptable daily intake (ADI): According to the European Food Safety Authority: An estimate of the amount of a substance in food or drinking water that can be consumed over a lifetime without presenting an appreciable risk to health. It is usually expressed as milligrams of the substance per kilogram of body weight and applies to chemical substances such as food additives, pesticide residues, and veterinary drugs.

Bioaccumulation: The accumulation of a substance, such as a toxic chemical, in tissues of living organisms. Bioaccumulation occurs when a substance is consumed at a faster rate than the rate of excretion or metabolic transformation of that substance.

Chemical residue: The concentration of a chemical compound or metabolites that remain in animal products after slaughter.

Chronic: Chronic illnesses or conditions develop gradually and may worsen over time.

Constituent: Any physical, chemical, biological, or radiological substance in water and wastewater.

Chemical of emerging concern (CEC): A chemical that is not currently regulated in drinking water. It may be a candidate for future regulation depending on its ecological toxicity, potential human health effects, public perception, or frequency of occurrence.

Cull: Selective slaughter of non-productive animals.

Cyst: The resting or dormant stage of a microorganism, usually bacteria or protozoa, that allows the organism to survive in unfavorable environmental conditions.

Dairy animal: Any lactating or potentially lactating animal, such as dairy cattle and dairy goats, whose milk or milk-derived product may be used for human consumption.

Direct potable reuse (DPR): A form of potable reuse. As defined in the California Water Code, direct potable reuse is the, "…planned introduction of recycled water either directly into a public water system, as defined in Section 116275 of the Health and Safety Code, or into a raw water supply immediately upstream of a water treatment plant."

Disinfected tertiary recycled water (DTRW): Filtered and disinfected wastewater that meets the criteria in Section 60301.230 of Title 22 of the California Code of Regulations.

Disinfection byproduct (DBP): Chemicals formed by the reaction of a disinfectant, such as chlorine or ozone, with organic or inorganic matter found in treated water or wastewater.

Disinfection*:* Rendering pathogens incapable of reproducing, thereby preventing their ability to cause illness. When referring to any microorganism, also known as inactivation.

Enteric: Relating to or residing in the intestines.

Half-life: The time required for the concentration of a chemical in the body to decrease by 50 percent through metabolism or elimination.

Fomite: Objects (for example, doorknobs), materials, or substances that can be contaminated with and then transfer infectious organisms.

Hazard: For the purposes of this report, a chemical, radiological, or biological agent that may cause an adverse health effect.

Indicator microorganism: An easily detectable microorganism that represents a broader microbial group of interest.

Ingestion: The oral consumption of a substance by an animal.

Lactation: The production and secretion of milk from mammary glands.

Livestock: Per California Assembly Bill (AB) 2071 and the California Water Code §13521.1(f), livestock is defined as, "…any domesticated bird, bovine animal, horse, mule, burro, sheep, goat, or swine." Dairy animals are not included in this definition.

Livestock watering: Providing water to livestock for drinking.

Log_{10} reduction: A reduction in the concentration of a constituent or microorganism by factors of 10. For example, a 1-log_{10} reduction is a reduction of 90 percent from the original concentration; a 2-log_{10} reduction corresponds to a reduction of 99 percent from the original concentration.

Log_{10} reduction credit: Value assigned to a specific treatment process to quantify (in log_{10} units) the technology's ability to inacativate or remove a specific microorganism or group of microorganisms. For example, a 1-log_{10} reduction credit indicates a 90 percent reduction and a 2-log_{10} reduction credit indicates a 99 percent reduction of the reference microorganism.

Oocyst: According to the Centers for Disease Control: A hardy, thick-walled stage of the life cycle of coccidian parasites. This is the stage that is shed in the feces of people infected with parasites such as *Cyclospora* and *Cryptosporidium.*

Ova: For this report, the egg produced by a pathogenic microorganism such as a helminth.

Pathogen: Microorganisms, such as bacteria, viruses, or protozoa; or a helminth egg capable of causing disease in people or animals.

Reclaimed water: This term is used synonymously with "recycled water." The State of California uses the term "recycled water" rather than "reclaimed water."

Recycled water: In the State of California, recycled water is defined in Section 13050(n) of the California Water Code as "water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur and is therefore considered a valuable resource."

Risk: In risk assessment, the probability of a hazard to cause harm combined with the severity of the harm.

Ruminants: Cud-chewing mammals with a four-compartment stomach comprised of the rumen, reticulum, omasum, and abomasum. Ruminants get nutrients from plant-based food through fermentation in a specialized stomach, the rumen, before digestion, principally through microbial action. Ruminants include cattle, goats, and sheep, among other mammals.

Safety: The practical certainty that a substance will not cause injury under carefully defined circumstances of use and concentration.

Source control: The elimination or control of constituents that are difficult to treat and/or may impair the wastewater treatment process and the final quality of the effluent if allowed to discharge into a wastewater collection system.

Surrogate microorganism: A microorganism used as a parameter capable of measuring treatment performance.

Treatment train: A grouping of treatment technologies or processes to achieve a water quality goal or objective.

Tolerable daily intake (TDI): An estimate, in milligrams per kilogram of body weight per day, of a substance that is not expected to result in any adverse health effects following chronic exposure to a population of livestock species or people, including sensitive subgroups.

Tolerance: The maximum allowable concentration of a marker residue (the parent compound or a metabolite that can be reliably quantified) in meat that is in a known relationship to the total residue.

Violative residue: Occurs when the concentration of a chemical residue or drug in meat or eggs exceeds an established regulatory threshold. Such thresholds may be called tolerances, maximum residue levels, or action levels, depending upon the regulatory agency and nature of the chemical.

Withdrawal time: The time between cessation of exposure to a chemical or drug and the time when the chemical's concentration in meat is below a regulatory limit or tolerance.

Xenobiotic: A substance that is foreign to the body or to an ecological system.

Zoonosis: A disease transmitted to people from animals or animal products.

ABBREVIATIONS FOR UNITS OF MEASURE

A	Acre = 43,560 ft^2
AF	Acre-foot (of water) = 325,851 gallons
CFU	Colony-forming unit
cm^2	Square centimeter
d	Day
ft^2	Square foot
g	Gram
kg	Kilogram
L	Liter
mg	Milligram
mg/L	Milligram per liter
Mgal	Million gallons
MGD	Million gallons per day
mi	Mile
min	Minute
mJ	Millijoule
mL	Milliliter
MPN	Most probable number
ng	Nanogram
ng/L	Nanogram per liter
NTU	Nephelometric turbidity unit
ppb	Parts per billion, ~micrograms per L (µg/L)
ppm	Parts per million, ~milligrams per liter (mg/L)
ppt	Parts per trillion, ~nanograms per liter (ng/L)
µg/L	Microgram per liter = parts per billion (ppb)
µm	Micrometer

EXECUTIVE SUMMARY

ES.1 Purpose and Scope

Water scarcity is a considerable threat to California's agricultural industry, which ranks first in the nation. Agricultural sales in 2016 were approximately $45.3 billion, making California the top state in cash farm receipts. The state's top agricultural commodities include cattle (~$2.5 billion) and chickens ($939 million). Livestock animal products including milk, beef, pork, and eggs, generate 27 percent of agricultural revenues in California. To maintain the health and productivity of livestock, California's farmers and ranchers must have reliable access to safe water for their animals.

Ensuring sufficient water supplies to support California agriculture is challenging, especially during recent droughts. Because climate modelers predict that arid regions in the United States will experience more extreme droughts in the future, it is important to develop alternative water supplies now to maintain high food production standards and protect California's economy.

Communities throughout California have invested in treatment processes to recycle water, which can offset the amount of potable water used for agricultural and industrial purposes. Recycled water is an approved alternative to groundwater or surface water for the irrigation of food, fodder, and fiber crops, along with other on-farm uses, and is regulated under Title 22 of the California Code of Regulations. Although Title 22 neither explicitly approves nor prohibits the use of recycled water for watering livestock, some California farmers have reported that they use recycled water for this purpose. These reports resulted in legislative scrutiny of the practice, including public hearings and legislation that directed the State Water Resources Control Board (State Water Board) to investigate the health implications of this currently unauthorized practice.

On February 20, 2014, during California's most recent historic drought, California Assembly Member Marc Levine (D-Greenbrae) introduced Assembly Bill 2071, which requires the State Water Board to ascertain whether, "*…the use of disinfected tertiary treated recycled water for the purpose of providing water to animals, as defined, would not pose a significant risk to public and animal health.*" According to Title 22, Disinfected Tertiary Recycled Water (DTRW) must be oxidized, filtered, and disinfected with chlorine or another process that is demonstrated to inactivate or remove a reference pathogen to a standard level. The regulation also prescribes filtration processes to meet a turbidity benchmark.

AB 2071 required the State Water Board to establish uniform statewide recycling criteria for using DTRW for livestock watering if using DTRW, as defined by Section 60301.230 of Title 22 of the California Code of Regulations,[1] would pose a significant risk to human or animal health. Governor Brown signed AB 2071, and it was codified as Section 13521.1 of the California Water Code on September 28, 2014.

1 Access the State Water Resources Control Board's regulations (Title 22) for recycled water at: http://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/RWregulations_20150716.pdf

In furtherance of these legislative objectives, and at the request of the State Water Board, NWRI formed an Independent Advisory Panel (the Panel) to provide expert scientific recommendations in response to questions presented by the legislature. In addition, the State Water Board asked the Panel additional questions, which the Panel refined to more closely address the requirements of AB 2071. These questions make up the Panel's charge, or scope of inquiry, for this effort.

NWRI organized and administered the Panel on behalf of the State Water Board. The Panel members are recognized nationally and internationally for their expertise in the following scientific or applied disciplines: veterinary medicine and clinical toxicology; animal physiology and metabolism; veterinary epidemiology; engineered water treatment processes and technologies; water quality and public health criteria; microbiology; and risk assessment. To learn more about the Panel members, see the **Acknowledgments** section, **Chapter 1**, or the appendix titled **Biographies of the Panel Members**.

Livestock Water, Porterville, California

Pursuant to direction from the State Water Board, the Panel evaluated risks associated with pathogenic (disease-causing) microorganisms and chemical contaminants in recycled water that may be harmful to people and livestock animals. Because the use of recycled water for livestock watering is not a common practice in the United States, there is limited information available on this topic.

The full Panel met three times during 2017 to review mandated and supplemental background materials, consider human health and livestock health implications, reach consensus, and formulate this Report. In addition, the Panel, the Panel Chair, two subject matter subcommittees, and NWRI staff met frequently throughout 2017 and 2018 to assemble their findings and finalize this Report.

After considering the available evidence, the Panel determined that although DTRW used for livestock watering is not likely to be a significant exposure pathway for chemicals or for pathogens compared to other exposure pathways, it would be premature to approve the use of Title 22 DTRW for livestock watering given the lack of animal dose-response data and long-term studies of herds that receive recycled water as their sole water source. **As a result, the Panel recommends that the State Water Board develop additional uniform water recycling criteria to include BMPs described in this report to ensure that DTRW used for livestock watering is protective of both livestock health and human health.**

ES.2 Relevant Recycled Water Requirements in California

Recycled wastewater has become an increasingly reliable source of supplemental water in the United States, with more than 25 states recycling water for beneficial uses. California began regulating the use of recycled water in 1977 to ensure the protection of public health and the environment. Current state legislation requires an increase in the production and use of recycled water in California to offset the use of drinking water for irrigation and other non-potable applications.

Title 22 currently specifies 43 approved uses for recycled water, including irrigation using DTRW on salad crops and fruits that come into direct contact with the recycled water. California farmers have irrigated salad and fruit crops with recycled water for more than 50 years, and no human illness caused by the practice has been documented. In addition, research has demonstrated that recycled water is safe to irrigate salad vegetables and strawberries; an 11-year analysis by a California water agency found no viruses on samples of crops grown with recycled water, and naturally occurring bacteria were equivalent to control samples. In addition, a quantitative risk assessment published in 2012 concluded that current agricultural water recycling regulations do not measurably increase public health risk.

While most uses defined by Title 22 are designed to manage risks to human health, some of the categories affect animals as well. These regulations allow the use of disinfected secondary recycled water, which is a less stringent water quality criteria than DTRW, to irrigate pastures for livestock that produce milk for human consumption. And undisinfected secondary recycled water, which likely contains more pathogens than disinfected water does, can be used to irrigate fodder crops and pasture for animals that do not produce milk for human consumption. Although the Title 22 regulation does not include guidance for livestock watering, anecdotal evidence suggests that this practice occurs in California. No reports of adverse effects on livestock health caused by using recycled wastewater for livestock watering were discovered during research for this report.

ES.3 Available Guidance and Information

Although the federal government has delegated authority to the State of California for water recycling regulations, the US Environmental Protection Agency (EPA) periodically issues *Guidelines for Water Reuse.* The 2012 *Guidelines* noted that recycled water generally is not used for livestock watering in the United States, but that *de facto* or unplanned recycled water reuse is a common practice. *De facto* reuse often occurs when communities downstream from wastewater treatment plants (WWTPs), including communities that support livestock, withdraw and use water from a surface water source that is partly or entirely composed of treated wastewater effluent.

The federal government has jurisdiction over animal health and safety, which is regulated by the US Department of Agriculture (USDA), EPA, Food and Drug Administration (FDA), and other agencies. Perhaps the best-known regulation is the Animal Welfare Act, passed by Congress in 1966 and enforced by USDA, which applies to animals bred for commercial sale, exhibited to the public, used in biomedical research, or transported commercially. The Act requires that animals be provided with "adequate potable water," but does not define "potable water." Notably, the requirements set forth in the Act do not extend to livestock, and certain animals are excluded from regulation, including horses that are not used for research purposes, along with livestock or poultry used as food for people or animals.

Other federal regulations are used to protect livestock from the adverse effects of many chemicals, particularly drugs and pesticides. The FDA determines if drugs and feed additives will accumulate in the tissues of food animals and has established minimum withdrawal times between the animal's last drug exposure and slaughter to ensure that chemical residues in meat are within safe limits for human consumption. In addition, the EPA establishes tolerances of pesticides in food animal products. A tolerance is the maximum allowable concentration of a marker residue that can be reliably quantified in edible animal food products, such as meat or eggs. Although the FDA and EPA both evaluate human acceptable daily intake (ADI) or health risks associated with chemicals in livestock products, they may use different calculations to assess these risks.

No states in the United States issue standards for trace-level contaminants specifically for livestock. Canada, however, has a risk-assessment process to evaluate chemicals in water that is given to livestock.

Regulations already exist or are being developed for the use of recycled water for livestock watering in Arizona, Colorado, Minnesota, Oklahoma, and Virginia. Meanwhile, other countries, including Australia and Canada, have published regulations that include criteria for using recycled water for livestock drinking water; the European Commission (EC) has proposed that the European Union adopt similar regulations soon.

Because of the lack of data on animal health and drinking water quality, the Panel assumed that the benchmarks developed for human drinking water would be conservative when applied to livestock, and they consulted several resources for human health risks. For example, the State Water Board convened a science advisory group in 2009 to develop monitoring strategies for chemicals of emerging concern (CECs) in recycled water with respect to human health risks; this group was reconvened in 2017 and published a report in 2018. The Panel considered the science advisory group's reports, as well as a 2010 report published by NWRI that evaluated the presence and fate of CECs in three major drinking water sources in Southern California. To date, no adverse human or animal health effects from exposure to the extremely low concentrations of CECs found in water supplies have been documented.

ES.4 Risks from Pathogens

All untreated wastewater is expected to contain pathogens. The Panel evaluated (1) potential health risks to both people and non-dairy livestock posed by pathogens in untreated municipal wastewater, and (2) the importance of reducing these risks when DTRW is used as a drinking water source for non-dairy livestock. Specifically, the Panel focused on waterborne pathogens that could affect the health of both livestock and people, disrupt food production if detected in animal tissue at levels of concern, or cause disease.

Because water industry treatment goals are designed for protection of human health, there is little data on wastewater-borne pathogens that infect animals. To overcome this lack of data on animal health, the Panel considered pathogens of human health concern that are found in DTRW and that may be used as surrogates or models for animal pathogens. These pathogens include:

- **Viruses:** Hepatitis E.
- **Bacteria:** *Salmonella enterica, Campylobacter* spp., and *Clostridium perfringens* spores.

- **Protozoa:** *Giardia lamblia*, *Cryptosporidium parvum*, *Neospora caninum*, and *Toxoplasmosa gondii*.

The Panel summarized data on these pathogens, including their presence in raw wastewater and the treatment processes used to remove them during water recycling. The Panel also addressed the microbial water quality of DTRW and implications for both human and animal health. After considering the available information, the Panel determined that although DTRW used for livestock watering is not likely to be a significant exposure pathway for pathogens when compared to other exposure pathways, it would be premature to approve the use of DTRW for livestock watering given the lack of animal dose-response data for pathogens that affect livestock and the importance of maintaining the highest standards in the California livestock industry. **Therefore, the Panel recommends that the State Water Board should require those who apply for a permit to use DTRW for livestock watering to implement additional pathogen control barriers.** The recommendations are summarized in Section ES.6.

ES.5 Risks from Chemicals

There is ample evidence that chemical concentrations found in DTRW are very low. The Panel evaluated the potential health risks to non-dairy livestock that are given DTRW as a sole source of drinking water and the potential health risks to humans from eating animal products from such livestock. In the absence of health-based benchmarks for non-dairy livestock, the Panel took a conservative approach to:

- Assessing potential effects on animal health;
- Estimating the concentrations of chemicals in animal products such as meat and eggs; and
- Evaluating potential adverse effects on human health from eating meat and eggs from livestock that are given DTRW.

The Panel determined that chemicals in DTRW do not pose a significant threat to the health of non-dairy livestock given the low concentrations of chemicals in DTRW and the availability of human health-based benchmarks to evaluate the risk. Furthermore, the Panel found no evidence that meat and eggs from animals that are given DTRW as their sole drinking water source would pose an adverse health risk to people, because of: (1) the conservative nature of estimating the chemical concentrations in meat and eggs; and (2) human health-based benchmarks, such as the acceptable daily intake, using well-established safety factors. **However, due to the lack of dose-response data for chemicals of concern in livestock animals, the Panel recommends that the State Water Board should require those who apply for a permit to use DTRW for livestock watering to implement a source control program that complies with the National Pretreatment Program and includes technically based local limits.** This recommendation is summarized in Section ES.6.

ES.6 Summary of Panel Recommendations

AB 2071 instructed the Panel to consider, at a minimum, the following criteria:

- Recommendations from the existing Advisory Panel on Constituents of Emerging Concerns in Recycled Water;
- State-funded research performed pursuant to Section 79144 and subdivision (b) of Section 79145; and
- Research by the State Water Board relating to unregulated pollutants.

On February 20, 2014, during California's most recent historic drought, California Assembly Member Marc Levine (D-Greenbrae) introduced California State Assembly Bill (AB) 2071 to require the State Water Board to ascertain whether "the use of disinfected tertiary treated recycled water for the purpose of providing water to animals, as defined, would not pose a significant risk to public and animal health." The Panel's approach to the questions posed by the Legislature yielded the short answers presented below:

Question: Would the use of disinfected tertiary recycled water (DTRW) for the purpose of providing water to animals, as defined, pose a significant risk to public health?

> **Conclusion:** Based on available evidence, the Panel was unable to determine if the use of DTRW as currently defined in Title 22 would not pose a significant risk to public health.

Question: Would the use of disinfected tertiary treated recycled water for the purpose of providing water to animals, as defined, pose a significant risk to animal health?

> **Conclusion:** Based on available evidence, the Panel was unable to determine if the use of DTRW as currently defined in Title 22 would not pose a significant risk to animal health.

Given the lack of dose-response data for pathogens and chemicals of concern for livestock health and human health, and the lack of studies on pathogen and chemical exposure for the specific livestock species noted in the legislation, the Panel recommends that the State Water Board adopt additional uniform recycling criteria (URC) for DTRW to be used for livestock watering, and recommends the following BMPs:

1. Require any DTRW system that provides drinking water to livestock to develop and maintain targeted source control that complies with the National Pretreatment Program and includes technically based local limits to exclude waste from slaughterhouses/abattoirs, zoos, other significant contributions of animal pathogens, and concentrated industrial chemical contaminants.
2. Require any DTRW system that provides drinking water to livestock to achieve disinfection using an approved ultraviolet (UV) system that meets the disinfection criteria in Title 22 for DTRW. The disinfection must, when combined with the filtration process, be demonstrated to inactivate and/or remove 99.999 percent of the plaque-forming units of F-specific bacteriophage MS2, or polio virus in the wastewater. The Panel agreed that UV disinfection is a more effective disinfectant than chlorine for many pathogens of concern.

3. Require any DTRW system that provides drinking water to livestock to maintain an appropriate disinfection residual in the DTRW distribution system to prevent microbial growth of opportunistic pathogens. The Panel recommends 0.2 mg/L free chlorine or 0.5 mg/L chloramine at the point of use.

The Panel also encourages the State Water Board to coordinate with relevant Federal and State agencies (such as USDA, FDA, or CDFA), veterinarians, and others who have a duty to report livestock animal health issues to track the health of animals in herds that receive DTRW through a periodic review and analysis of animal health monitoring data.

In addition, the Panel discussed seven questions provided by the State Water Board. These questions addressed whether credible scientific evidence was available to determine that using DTRW for livestock watering is protective of the health of livestock and the people who eat meat and eggs from livestock provided with DTRW. The Panel's responses are provided in **Chapter 6.**

Recommended Research

The Panel agreed that additional research is not required to adopt new uniform recycling criteria for DTRW used for livestock watering. However, the Panel recommends that the State Water Board consider undertaking the following research when resources are available to do so:

1. Evaluation of updated data on raw water concentrations and the pathogen reductions previously reported by Rose et al. (2004). The data are currently being developed.

2. Characterization of concentrations of pathogens of animal health concern. Such pathogens include mycobacteria, *Clostridium* spp., antimicrobial-resistant (AMR) microorganisms, reoviruses, microsporidia, prions, and other known or emerging pathogens of concern in raw wastewater. Such research could clarify the health significance of these pathogens, particularly for sensitive livestock populations.

3. A controlled study in which DTRW is provided as the sole water source for a livestock herd (i.e., beef cattle, goats, sheep, broiler chickens, or laying hens) for an extended period to assess the effects on livestock health and to measure concentrations of selected CECs or other chemicals in edible tissues. Tissue analysis should include CECs that are more environmentally stable and may bioaccumulate.

4. Assessment of whether a tiered chemical surveillance approach similar to that employed by the USDA Food Safety Inspection Service should be developed.

5. Investigation of new performance measures, such as biodegradable dissolved organic carbon (BDOC) and the incorporation of validated bioanalytical screening techniques that could improve current monitoring programs.

PART 1: BACKGROUND

CHAPTER 1: INTRODUCTION

- Organization of the report
- Background on California Assembly Bill No. 2071, Chapter 731, and the California Water Code Section 13521.1, including questions provided by the State Water Resources Control Board and Panel assumptions
- Purpose and activities of the Independent Advisory Panel (Panel)
- Findings and recommendations of the Panel

An Independent Advisory Panel (Panel) of six experts in water science and animal health, referred to as the Panel, was formed in 2016 by the National Water Research Institute (NWRI) on behalf of the State Water Resources Control Board (State Water Board) to assess whether the use of disinfected tertiary recycled water (DTRW) as a source of drinking water for commercially produced non-dairy livestock in California poses any significant health risks to people or livestock. This effort was undertaken to fulfill the requirements of California Assembly Bill No. 2071, Chapter 731 (signed into law in September 2014) and Section 13521.1 of the California Water Code (effective January 2015).

Brief descriptions of the legislative and regulatory requirements are provided in this chapter, along with background information about the Panel and its activities. In addition, this chapter describes how the report was developed and organized, including the seven overarching questions addressed by the Panel to complete its charge, and the underlying approach and assumptions used by the Panel to make its assessment and achieve consensus.

1.1 Organization of the Report

The Panel report is organized into three parts that focus on:

1. Background information related to the Panel's charge;
2. Purpose and activities of the Panel; and
3. Findings and recommendations of the Panel.

1.2 Background on the Regulation

From January 17, 2014, to April 7, 2017, Governor Edmund G. Brown declared a State of Emergency in the State of California because of a record-breaking drought. During this time, state officials were directed to take all necessary actions to prepare for drought conditions (USGS, 2017). The State of Emergency mandated water conservation to reduce water use and increased efforts to use recycled water as an alternative water supply.

Water scarcity threatens California's agricultural industry, which leads the nation in agricultural production and exports. Farmers and ranchers in California produce more than 400 commodities, including field crops such as cotton and alfalfa hay; floriculture such as cut flowers and bedding plants; fruit and nuts; wine grapes and raisins; vegetables and melons; and livestock and dairy products such as meat, eggs, milk, cream, and cheese.

California ranks first nationally in farm production. In 2016, California's 77,500 farms and ranches received $47.1 billion for their output. In comparison, the state of Iowa is ranked second nationally and reported farm receipts of $27.8 billion in the same period (CDFA, 2016).

About 73 percent of agricultural revenue in California is generated from crops, while 27 percent is from livestock products such as milk, beef cattle, eggs, sheep, turkeys, hogs, and horses. Dairy products are California's most valuable livestock products, followed by cattle, calves, and chicken eggs (Netstate, 2016). Significantly, livestock and livestock products from California account for more than 6 percent of total livestock cash receipts, totaling $12 billion in 2015, in the United States (CDFA, 2016).

A readily available, safe, and reliable water supply is vital to ensuring the health and productivity of livestock. Water is used for drinking and for cooling, sanitation, and waste disposal. The daily amount of drinking water needed varies depending on the species, age, weight, and stage of production, such as laying eggs or lactating. For example, individual beef cattle may weigh from 300 pounds to more than 1,400 pounds, and daily water intake can range from 3 to 30 gallons per day per animal.

Local temperature is another important factor for livestock watering. During cold weather, cattle require approximately 1 gallon per 100 pounds of body weight per animal per day. During hot weather, the volume increases to 2 gallons per 100 pounds per animal per day. **Table 1-1** shows the approximate daily water intake for beef cattle relative to temperature (Rasby, 2016; Rasby and Walz, 2011).

Water shortage and drought can limit access to suitable livestock water supplies. For instance, as surface water levels decrease, or as water stagnates, nutrients such as nitrates and other organic and inorganic compounds can accumulate and deteriorate water quality. The consequences of a water shortage on livestock health can include nutritional deficiencies, reproductive difficulties, sickness, and death.

Compromised animal health and productivity due to water shortages can create economic and commercial consequences for the livestock industry. Animals that are not provided with sufficient water to drink may be underweight, which costs producers who are paid by animal weight, or may be underproductive, such as hens laying fewer eggs; these characteristics may lead to the unnecessary liquidation or slaughter of animal stocks.

Table 1-1. Approximate Total Daily Water Intake of Beef Cattle[a]
Based on temperature and animal weight (adapted from Rasby and Walz, 2011)

Temperature in **°F** [b]	40°	50°	60°	70°	80°	90°
Weight in Pounds [c,d]	Gallons	Gallons	Gallons	Gallons	Gallons	Gallons
Growing Heifers, Steers, Bulls						
400	4.0	4.3	5.0	5.8	6.7	9.5
600	5.3	5.8	6.6	7.8	8.9	12.7
800	6.3	6.8	7.9	9.2	10.6	15.0
Finishing Cattle						
600	6.0	6.5	7.4	8.7	10.0	14.3
800	7.3	7.9	9.1	10.7	12.3	17.4
1,000	8.7	9.4	10.8	12.6	14.5	20.6
Wintering Beef Cows						
900	6.7	7.2	8.3	9.7	--	--
1,100	6.0	6.5	7.4	8.7	--	--
Mature Bulls						
1,400	8.0	8.6	9.9	11.7	13.4	19.0
1,600+	8.7	9.4	10.8	12.6	14.5	20.6

[a] 1996 National Research Council Nutrient requirements of Beef Cattle, Seventh Revised Edition, 1996. Table derived from an article by C. F. Winchester and M. J. Morris, Vol 15, No 3, Journal of Animal Science, August 1956.

[b] Water consumption is a function of dry matter intake and ambient temperature. Water consumption is constant up to 40°F.

[c] Dry matter intake influences water consumption. Heavier cows are assumed to be in greater body condition and require less dry matter and, therefore, less water.

[d] Cows larger than 900 pounds are included in this recommendation.

Figure 1-1 shows California's geographical regions of beef cattle production and number of cattle, relative to the severity of drought conditions. This illustrates the threat of water scarcity to livestock production.

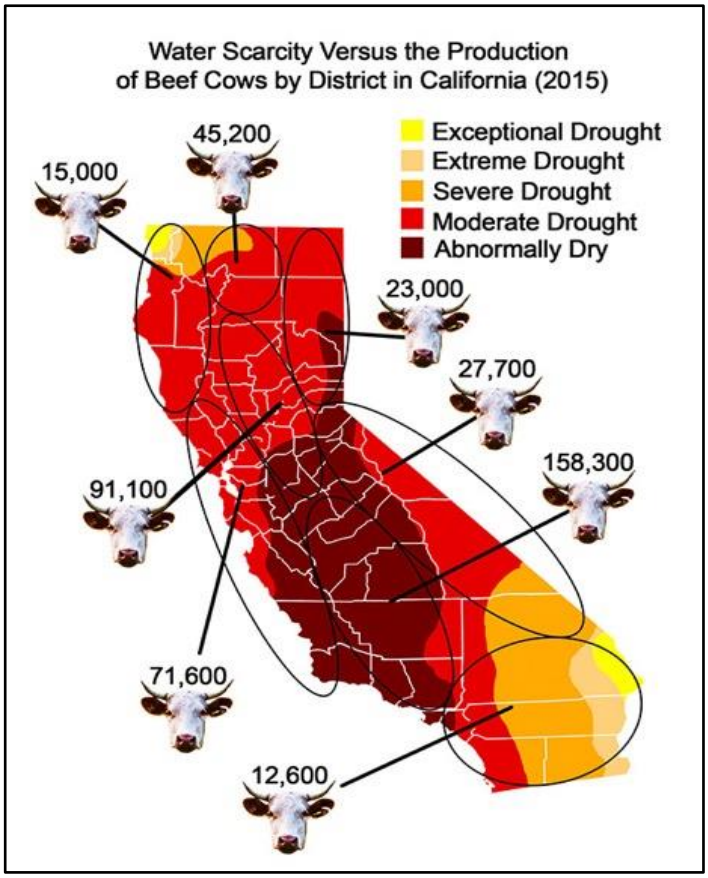

Figure 1-1. Comparison of regions experiencing drought to regions of beef cattle production in California. Data from Drought Monitor (2015) and CDFA (2016).

Recycled water is considered a suitable alternative to groundwater or surface water for agricultural irrigation and other on-farm uses. The EPA *2012 Guidelines for Water Reuse* provide information about using recycled water for agricultural purposes, specifically noting that:

> The California Water Recycling Criteria (Title 22 of the state Code of Regulations) require the most stringent water quality standards with respect to microbial inactivation (total coliform <2.2 CFU/100 mL). California Water Recycling Criteria requires a specific treatment process train for the production of recycled water for unrestricted food crop irrigation that includes, at a minimum, filtration and disinfection that meets the state process requirements (EPA, 2012).

While Title 22 of the California Water Recycling Criteria allows the use of recycled water for agricultural crop irrigation and a number of other applications, it does not specifically address the use of recycled water as a source of drinking water for livestock. Accordingly, "some water providers have interpreted that to mean the practice is allowed and, in fact, it has been used in some parts of California" (Rendon, 2014). In a *Press Democrat* news article from February 2014, the author stated that, "Some farmers are using treated wastewater for their animals and have been doing so for years. It's unclear whether that violates any laws" (Moore, 2014). In response to these issues, Assembly Member Marc Levine of the Tenth Assembly District (representing the North San Francisco Bay Area) introduced *California Assembly Bill No. 2071: Recycled Water for Livestock* on February 20, 2014. The bill reads, in part, as follows:

> **AB 2071, Levine. Recycled Water: Animals.**
>
> Existing law requires the State Water Resources Control Board to establish uniform statewide recycling criteria for each varying type of use of recycled water where the use involves the protection of public health.
>
> This bill would require, by December 31, 2016, the state board, in consultation with impacted state agencies, to determine whether the use of disinfected tertiary treated recycled water for the purpose of providing water to animals, as defined, would not

> pose a significant risk to public and animal health. This bill would require the state board to establish uniform statewide recycling criteria for the use of recycled water for the purpose of providing water to animals if the state board determines that the use of disinfected tertiary treated recycled water for this purpose would pose a significant risk to public or animal health. The bill would authorize the state board to approve the use of disinfected tertiary treated recycled water for this purpose if the state board determines that its use would not pose a significant risk to public or animal health but would prohibit the use of disinfected tertiary treated recycled water in the water supply for dairy animals that are currently producing dairy products for human consumption.[2]

According to Levine (2017), AB 2071 was designed to, "…ensure that the highest level of treated water (tertiary) is safe to be used for livestock watering. Additionally, it would provide clarity in the regulation of livestock watering."

At the same time, an Expert Panel was convened by WateReuse California (WRCA) in 2014 to "identify the key issues and provide insights into the level of risk" that might result from the use of DTRW as a drinking water supply for livestock. The WRCA Panel conducted a series of meetings in February 2014 and published a 17-page position paper on February 25, 2014 (Atwill et al., 2014). The document reflects the collective perspective of scientists and veterinarians who had valuable input into the discussion based on their expertise and experience, and is intended to define the perceived risks to animals and the public, stating:

> Based on the tertiary treatment as defined in Title 22, we expect some pathogens and contaminants to be present in tertiary sewage effluent. We have assessed the overall risk of providing livestock with this water for drinking relative to the alternative risk of the animals running out of drinking water altogether. The risk from any water will never be zero. Title 22 standards are stringent, however, and the need for a safe source of drinking water is urgent. We believe that in this emergency situation, the overall benefits of feeding tertiary drinking water to livestock in California outweigh the risks (Atwill et al., 2014).

The WRCA Panel's position paper is summarized in **Chapter 3**.

On February 27, 2014, a public hearing was held in the City Council Chambers of Petaluma, Sonoma County, California, by the Select Committee on Agriculture and the Environment on the potential use of highly treated recycled water for livestock.[3] The committee was chaired by Assembly Member Levine, and speakers included representatives from Sonoma County Water Agency, California Department of Public Health, San Francisco Bay Area Regional Water Quality Control Board, WateReuse California, University of California Davis School of Veterinary Medicine, and others. The bill received support from the following organizations:

- Association of California Water Agencies

2 http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB2071.

3 https://a10.asmdc.org/press-release/assembly-select-committee-agriculture-and-environment-meet-petaluma.

- California Association of Sanitation Agencies
- California Farm Bureau Federation
- Marin County Farm Bureau
- Sonoma County Farm Bureau

On September 28, 2014, Governor Brown approved AB 2071, Chapter 731, which added Section 13521.1[4] to the California Water Code requiring the State Water Board to "determine whether the use of disinfected tertiary treated recycled water, as defined by Section 60301.230 of Title 22 of the California Code of Regulations, for the purpose of providing water to animals, would not pose a significant risk to public and animal health." Refer to **Appendix 1A** for the complete legislative text.

The State Water Board is responsible for establishing uniform statewide water recycling criteria for each use of recycled water where the use involves the protection of public health. Under AB 2071, the State Water Board was given the authority to approve the use of DTRW for livestock watering if it was determined that DTRW would not pose a significant risk to human or animal health. Notably, the bill prohibited the use of DTRW in the water supply for animals that produce dairy products for human consumption.

Section 13521.1 of the California Water Code became effective January 1, 2015. Among other provisions, it directed the State Water Board to consider the following resources when evaluating the use of DTRW for animal use:

- Recommendations from the Advisory Panel on Chemicals of Emerging Concern in Recycled Water (Anderson et al., 2010; Yamamoto, 2010).
- State-funded research performed pursuant to Section 79144 and subdivision (b) of Section 79145 of the California Water Code (Olivieri et al., 2016; State Water Board, 2016).
- Research relating to unregulated contaminants (Drewes et al., 2008; Guo et al., 2010; NWRI, 2013; Sedlak and Kavanaugh, 2006; West Basin Municipal Water District, 2006).

In this context, "animal" was defined in the California Water Code, Section 13521.1(f), as "any domesticated bird, bovine, horse, mule, burro, sheep, goat, or swine."

1.3 Purpose and Activities of the Independent Advisory Panel

The State Water Board used a third-party group of experts to assist with meeting the requirements of Section 13521.1 of the California Water Code. In 2016, NWRI signed a contract under State of California Standard Agreement #15-099-400 to organize and facilitate an Independent Advisory Panel on behalf of the State Water Board to determine if DTRW for livestock watering poses any significant risk to public or animal health. See **Appendix 1B** for information on NWRI Panels.

4 Refer to http://law.onecle.com/california/water/13521.1.htmlto access Section 13521.1 of the California Water Code.

Working with NWRI and the State Water Board, the Panel refined its charge to evaluate whether the use of DTRW as a primary source of drinking water for non-dairy livestock poses any significant risks to animal health or to people who eat animal products. This report is the product of that evaluation.

1.3.1 Panel Members

The Panel consisted of six professionals who met the State Water Board[5] requirements that the Panel "should be comprised, at a minimum, of a veterinarian with pasture animal experience, a toxicologist, an engineer with wastewater experience, a chemist, a microbiologist, an expert in risk assessment, and an epidemiologist." The Panel members are:

- Panel Chair: Robert Poppenga, DVM, PhD, DABVT, California Animal Health and Food Safety Laboratory, School of Veterinary Medicine, University of California
- Nicholas Ashbolt, PhD, School of Public Health, University of Alberta
- Andrea Mikolon, DVM, MPVM, PhD, Animal Health Branch, California Department of Food and Agriculture
- Brian Pecson, PhD, PE, Trussell Technologies, Inc.
- Channah Rock, PhD, University of Arizona
- David J. Smith, PhD, Animal Metabolism-Agricultural Chemicals Research, United States Department of Agriculture, Agricultural Research Service

Brief biographies of Panel members are provided in the Appendix.

1.3.2 Panel Activities

The Panel met three times in 2017 to review available data and report on their findings. The first Panel meeting was on February 14, 2017, at the Orange County Water District in Fountain Valley, California. At this meeting, the Panel received background on the legislation and an overview of the issues as stated by the State Water Board. The Panel divided into Chemical and Pathogen Working Groups to research and address these issues. The Working Groups included:

- Chemicals: Robert Poppenga and David J. Smith
- Pathogens: Nicholas Ashbolt, Andrea Mikolon, Brian Pecson, and Channah Rock

Both Working Groups planned and discussed topics in advance of the second Panel meeting, which was on May 5, 2017. The Panel met at the California Animal Health & Food Safety Laboratory of the School of Veterinary Medicine at the University of California, Davis. Discussion during the second meeting focused on interim results of the Chemical and Pathogen Working Groups and refining the process used to develop the report, including overall structure, information to include, and topics to address. NWRI drafted a report outline, and the Panel held a conference call on July 12, 2017, to discuss writing assignments and basic assumptions for developing the first draft.

5 Per Agreement No. 15-099-400 issued to the National Water Research Institute by the State Water Resources Control Board.

The third Panel meeting was on August 7, 2017, at the Orange County Water District in Fountain Valley, California. Its purpose was to review the first draft of the report and agree on findings and recommendations. Subsequent work on the report was completed by email and conference calls. NWRI submitted the final report to the State Water Board in September 2018.

1.4 Questions Provided by the State Water Resources Control Board

On February 20, 2014, during California's most recent historic drought, California Assembly Member Marc Levine (D-Greenbrae) introduced California State Assembly Bill (AB) 2071 to require the State Water Board to ascertain whether "*the use of disinfected tertiary treated recycled water for the purpose of providing water to animals, as defined, would not pose a significant risk to public and animal health.*" The bill required the State Water Board to establish uniform statewide recycling criteria for the use of recycled water for the purpose of providing water to animals if using DTRW, as defined by Section 60301.230 of Title 22 of the California Code of Regulations,[6] would pose a significant risk to public or animal health. Governor Brown signed AB 2071, and it was codified as Section 13521.1 of the California Water Code, on September 28, 2014.

To assist the Panel in providing valuable input, the State Water Board provided 12 questions to (1) assist the Panel in its efforts to address the Panel charge and (2) help the State Water Board meet the requirements of AB 2071. The original 12 questions are listed in **Appendix 1C.** The Panel reviewed the 12 questions during their first meeting and refined the list to questions that either clarify issues and challenges or identify topics outside the scope of AB 2071 (see **Appendix 1D).** The final seven revised questions are:

1. Is there credible scientific evidence indicating that livestock provided with DTRW as the only water source experience any adverse health effects from either pathogens or chemicals present in the water? If so, what is the strength of the evidence?
2. Is there credible scientific evidence that humans who eat animal products, such as skeletal muscle, kidney, liver, fat, eggs, and, for poultry, skin with adhering fat, derived from livestock whose only water source is DTRW experience adverse health effects from either pathogens or chemicals present in the water? If so, what is the strength of the evidence?
3. If there is little to no scientific evidence of an adverse health effect to livestock or humans due to watering livestock with DTRW, are there any plausible risks to the health of livestock or humans based upon known pathogens and/or chemicals in water? If a potential adverse effect(s) is identified, how could the effect(s) be quantified scientifically?
4. Are the assumed pathogen and chemical risks of adverse health effects for humans applicable to livestock?
5. Is it possible to assess the relative risk of pathogen or chemical exposure between livestock populations that are provided with DTRW as the only water source versus livestock

6 Access the State Water Resources Control Board's regulations (i.e., Title 22) for recycled water at: http://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/RWregulations_20150716.pdf

populations that are provided with other sources of water, such as municipal, well, or surface sources?

6. If adverse health risks are not identified, what monitoring programs (if any) would be recommended to identify potential new or emerging risks?
7. If livestock or human health risks are identified or are plausible, are mitigation mechanisms possible to minimize and/or eliminate the risks (e.g., additional treatment steps or recommended withdrawal times for livestock)?

These questions are addressed in **Chapter 6**.

1.5 Panel Assumptions

The Panel covered an array of disciplines, including water reuse, human and livestock health concerns, risk management, and animal husbandry. To address this charge, the Panel first developed a decision logic to determine:

1. Which animal populations and species were within the scope of the Panel's charge;
2. What providing DTRW or exposure to DTRW entails;
3. Risks to human and livestock health; and
4. Other factors that are essential to achieving consensus on conclusions and recommendations.

1.5.1 Definition of Disinfected Tertiary Recycled Water

The source water under consideration by the Panel was DTRW, as defined by Section 60301.230 of Title 22 of the California Code of Regulations, which states:

> **§60301.230. Disinfected tertiary recycled water** means a filtered and subsequently disinfected wastewater that meets the following criteria:
>
> (a) The filtered wastewater has been disinfected by either:
>
> > (1) A chlorine disinfection process following filtration that provides a CT (the product of total chlorine residual and modal contact time measured at the same point) value of not less than 450 milligram-minutes per liter at all times with a modal contact time of at least 90 minutes, based on peak dry weather design flow; or
> >
> > (2) A disinfection process that, when combined with the filtration process, has been demonstrated to inactivate and/or remove 99.999 percent of the plaque forming units of F-specific bacteriophage MS2, or polio virus in the

wastewater. A virus that is at least as resistant to disinfection as polio virus may be used for purposes of the demonstration.[7]

(b) The median concentration of total coliform bacteria measured in the disinfected effluent does not exceed a Most Probable Number (MPN) of 2.2 per 100 milliliters utilizing the bacteriological results of the last seven days for which analyses have been completed, and the number of total coliform bacteria does not exceed an MPN of 23 per 100 milliliters in more than one sample in any 30-day period. No sample shall exceed an MPN of 240 total coliform bacteria per 100 milliliters.

For further clarification, "filtered wastewater" was defined as follows in Section 60301.320:

§60301.320. Filtered wastewater means an oxidized wastewater that meets the criteria in subsection (a) or (b):

(a) Has been coagulated and passed through natural undisturbed soils or a bed of filter media pursuant to the following:

(1) At a rate that does not exceed 5 gallons per minute per square foot of surface area in mono, dual or mixed media gravity, upflow or pressure filtration systems, or does not exceed 2 gallons per minute per square foot of surface area in traveling bridge automatic backwash filters; and

(2) So that the turbidity of the filtered wastewater does not exceed any of the following:

(A) An average of 2 Nephelometric Turbidity Units (NTU) within a 24-hour period;
(B) 5 NTU more than 5 percent of the time within a 24-hour period; and

(C) 10 NTU at any time.

(b) Has been passed through a microfiltration, ultrafiltration, nanofiltration, or reverse osmosis membrane so that the turbidity of the filtered wastewater does not exceed any of the following:

(1) 0.2 NTU more than 5 percent of the time within a 24-hour period; and
(2) 0.5 NTU at any time.

§60301.650. Oxidized wastewater means wastewater in which the organic matter has been stabilized, is nonputrescible, and contains dissolved oxygen.

1.5.2 Animals under Consideration

Section 13521.1(f) of the California Water Code defines animals as "any domesticated bird, bovine animal, horse, mule, burro, sheep, goat, or swine." The Panel noted that the California Water Code (and, therefore, this definition) applies only to animals commercially domiciled in the State of California. The Panel refined the definition of "animal" to refer to commercially produced non-dairy livestock: commercial poultry, non-dairy cattle such as beef cattle, horses, mules, donkeys, non-dairy sheep,

7 The Panel provided the following clarification in regard to criterion 1(a)(2) in §60301.230: As spiking with poliovirus is no longer allowed, any virus that is at least as resistant to disinfection as polio virus may be used for the purposes of log-reduction validation.

non-dairy goats, and swine. These animals could be raised on farm pastures, or confined facilities such as concentrated animal feeding operations (CAFOs)—a feedlot.

Although the Panel did not specify an age range for the livestock it considered, it acknowledges that disease can reduce the health and lifetime productivity of young animals more significantly than older animals. In general, the lifespan of livestock varies based on the type of animal and animal operation. For example, veal calves are slaughtered within a few months of birth, whereas beef cows could be slaughtered at ages of 5 to 8 years.

1.5.3 Exclusion of Dairy Animals

The Panel excluded dairy animals from its assessment because, as stipulated in Section 13521.1(c) of the California Water Code, "Disinfected tertiary recycled water shall not be used in the water supply for dairy animals that are currently producing dairy products for human consumption." In this report, dairy animals include dairy cattle and heifers, dairy goats and dairy sheep, doeling goats and ewe lambs to be included in dairy herds, and water buffalo.

Although the California Water Code specified that currently lactating animals would not receive DTRW, the Panel determined that animals that will eventually join a lactating herd should also be excluded from using DTRW. As such, dairy animals were defined for the purposes of this report as "any lactating or potentially lactating animal whose milk or milk-derived product may be used for human consumption." For instance, lactating animals would include milking cows and goats, while potentially lactating animals would include replacement heifers or does or "dry" animals that are not lactating currently but will be returned to the lactating herd after giving birth. Male cattle of dairy-producing breeds are not considered dairy animals for the purposes of this report.

For its evaluation, the Panel decided to exclude potentially lactating animals from using DTRW. The Panel concluded that it is not sufficient to stop or withdraw DTRW for a period before the production or use of the milk product, as this withdrawal period may not reduce the acceptable risk of infection.

Dairy cattle in California. Photo by Andrea Mikolon.

1.5.4 Other Animals Not under Consideration

The Panel determined it would be outside its scope of work to address health risks of DTRW for:

- Exotic zoo animals, in particular, animals related to domestic livestock species.
- Non-commercial backyard chickens and their eggs.
- Household pets, such as dogs, cats, birds, or aquarium fish.

- Fish reared in hatcheries or in aquaculture settings for food.
- Stressed animals in the livestock population.

The Animal Welfare Act, which regulates the treatment of animals in research, exhibition, transport, and by dealers, requires that potable water must be given to zoo animals (USDA, 2017). Therefore, these animals will not receive DTRW as a permitted source of water supply.

The Panel questioned whether household pets and backyard chickens would come into contact with DTRW at homes or businesses that use dual-plumbed systems, which supply both potable and recycled water. These animals have two opportunities for contact with DTRW through dual plumbing: (1) internal uses such as toilet and urinal flushing (allowed in Section 60307 of the California Water Code), and (2) residential landscape irrigation. With each of these applications, users are instructed by the appropriate permitting agency to use dual-plumbed recycled water only for its intended purposes. Therefore, the Panel assumed that household pets and chickens would have limited contact with DTRW and would not receive it as a water source.

For fish reared in hatcheries or in aquaculture settings for food, the Panel noted that per Section 60305 of the California Water Code, recycled water used as a source of supply for, "…any publicly accessible impoundments at fish hatcheries shall be at least disinfected secondary-2.2 recycled water," which receives less treatment than DTRW. Therefore, DTRW is cleaner than the recycled water already permitted by the State for use at fish hatcheries with publicly accessible impoundments. (**Chapter 2** includes a discussion of the different types of recycled water permitted in California).

The Panel did not differentiate between stressed and non-stressed animals in the general livestock population. This distinction would require substantial research and resources outside of the Panel's scope of work.

1.5.5 Permitting Authorities and Users of Disinfected Tertiary Recycled Water for Livestock Watering

For this evaluation, "users" include non-dairy livestock facilities, such as farms, ranches, feedlots, and other entities with a permit from the State to, "…use DTRW for the purpose of providing water to animals," per Section 13521.1 of the California Water Code. Regional Water Quality Control Boards would issue these permits under appropriate terms and conditions designed to protect public health.

1.5.6 Providing Disinfected Tertiary Recycled Water to Livestock

According to Section 13521.1 of the California Water Code, DTRW would be used for, "…the purpose of providing water to animals." Although the term "providing" could refer to a number of uses, the most direct route of exposure to potential microbial or chemical contaminants would be through drinking water. For this evaluation, the Panel assumed that: (1) livestock receive DTRW as the primary source of drinking water, and (2) livestock ingest the water orally. The Panel also considered that DTRW drinking water could span the lifetime of the animal, from weeks to years.

DTRW would be one source of water for livestock among a number of existing options. DTRW might be the primary source of water, or it might be used as a supplemental or seasonal source. Using DTRW

would be elective; per Section 13521.1(d) of the California Water Code, users "…shall not be required to use disinfected tertiary treated recycled water for the purposes [of providing water to animals]."

1.5.7 Variability in Water Supplies Currently Provided to Livestock

The standards for water supplies provided to both dairy and non-dairy livestock are listed in the California Food and Agricultural Code, Division 15, Part 1, Chapter 5, Article 3 (FAC, 1967), which states:

> **33515.** The water supply for the milk house or room and dairy barn shall be properly located, constructed, and operated, easily accessible, adequate, protected against contamination, and of safe and sanitary quality. The bacterial quality shall conform to the standards of the State Board of Health for public supplies of drinking water.
>
> **33516.** The water supply for drinking by livestock shall not be stagnant, polluted with manure, urine drainage, decaying vegetable or animal matter, or pathogenic bacteria of any source.

The Panel recognized that the source and quality of water supplies for non-dairy livestock in California will vary by region and facility. Source waters could include groundwater pumped from private wells; surface water from rivers, streams, ditches, and ponds; municipal drinking water; and stormwater. Variations in water quality may be caused by fecal and urinary contamination of local surface water, such as ponds and puddles, by livestock or wildlife.

1.5.8 Forms of Livestock Exposure Not Addressed by the Panel

The Panel did not address livestock consumption of fodder crops irrigated with DTRW, because this practice is already allowed per Section 60304(d) of Title 22 of the California Code of Regulations.[8] Although this report deals primarily with potential hazards from drinking DTRW, the Panel recognized that livestock also could be exposed to microbial or chemical contaminants through dermal contact with wash water or by inhaling aerosolized water in cooling mists used for heat abatement. The Panel assumed that:

- The risk from microbes is negligible compared to the levels of exposure to microbial contaminants through defecation or drift, as well as through non-disinfected surface water sources commonly used on farms.
- The risk of chemical exposure through DTRW is negligible because commercial animals are infrequently exposed to cooling mists and washes during their lifetime, and the concentrations of chemical contamination typically encountered in DTRW are low.

8 Refer to Title 22, Article 3 (Uses of Recycled Water), §60304 (Use of recycled water for irrigation), which states: "(d) Recycled wastewater used for the surface irrigation of the following shall be at least non-disinfected secondary recycled water," including (4) "Fodder and fiber crops and pasture for animals not producing milk for human consumption."

The Panel **did not** consider the following chemical contaminant exposures:

- Exposure of livestock to metabolites or degradation products, as well as exposures to chemical mixtures, except in rare instances in which such exposures might be incorporated into the design of a referenced toxicological study (as discussed in **Chapter 5**).
- Exposure of livestock to other sources of chemicals, such as medicated or contaminated feed.
- Introduction of chemical contaminants beyond the point of supply.

1.5.9 Routes of Human Exposure

The Panel assumed that people could be exposed to potential hazards from DTRW for livestock watering through the following pathways. **Figure 1-2** illustrates potential human exposure routes.

1. Ingestion of meat and eggs from livestock that consume DTRW.
2. Transmission of communicable diseases from infected livestock to people, particularly workers at livestock facilities using DTRW, through animal feces, saliva, blood, and other means. This transmission pathway assumes that the disease is from a microbial constituent in the water supply.

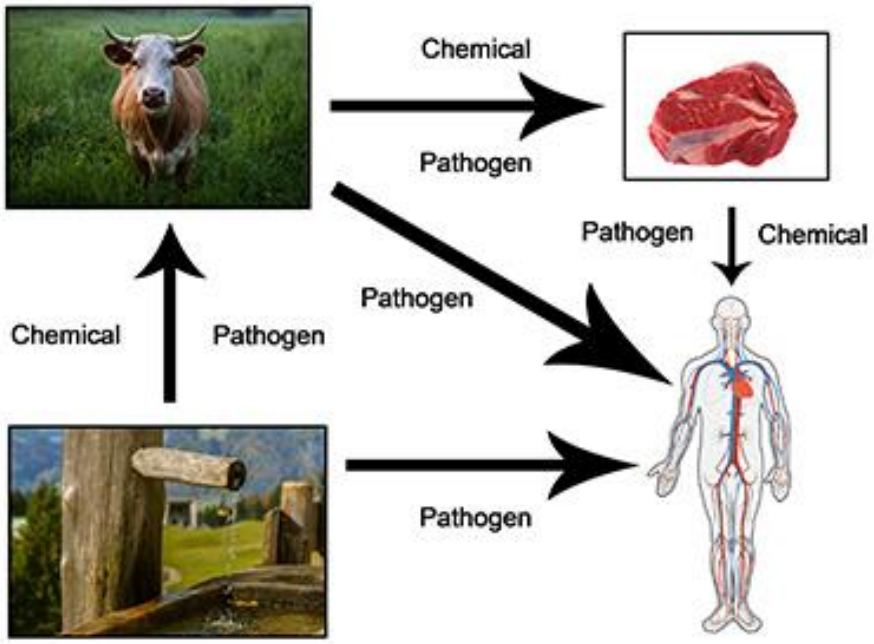

Figure 1-1. Potential route of exposure to microbial and chemical risks associated with the use of DTRW as a source of drinking water for non-dairy livestock.

1.5.10 Definition of Adverse Health Effect to Humans and Livestock

To determine whether using DTRW poses any significant risks to human or livestock health, the Panel first defined the term “adverse health effect” for this report as “the causation, promotion, facilitation,

and/or exacerbation of a structural and/or functional abnormality." The implication was that the abnormality produced has the potential to measurably:

1. Lower the quality of life for people, or, in the case of livestock, negatively affect animal welfare.
2. Contribute to a disabling illness that affects people or livestock.
3. Lead to a premature death in people or livestock, or the premature slaughter or culling from livestock herds.
4. Affect reproduction, fecundity, and/or fetal viability in people or livestock.
5. Affect animal productivity, including reductions in expected levels of food (meat or eggs) or fiber (wool).
6. Affect food animal acceptability, including (a) unanticipated microbial or chemical adulteration[9] of animal products intended for human consumption, or (b) carcass condemnation. While this does not technically impact animal health, food animal acceptability can affect the economics of food animal production the same way as an animal disease.

Adverse health effects may be caused by acute or chronic exposures[10] to pathogens or chemicals.

1.5.11 Other Risk Scenarios Considered by the Panel

The Panel considered scenarios in which DTRW could be a source of contagion if a disease originates from microbes in the water supply. One such scenario would be the introduction of a novel pathogen strain from the human population into livestock. For example, if livestock are exposed to new strains of *Salmonella* or antimicrobial resistant (AMR) bacteria that have not been seen in the host species, such novel bacterial strains could become established in domestic livestock. Another scenario could include the reintroduction of pathogens that are nearly eradicated from the livestock population, such as *Mycobacterium bovis,* which causes tuberculosis in cattle and can be transmitted from people to animals, and vice versa. For these types of scenarios, the risks could include morbidity and mortality in livestock, condemning animal products, culling of animal populations, and public health threats. Such scenarios could negatively affect food safety or consumer confidence in the food, livestock, and water industries.

The Panel also recognized that once an animal is infected, that animal has the potential to spread infection to other susceptible animals within the herd or flock. The effects could be amplified if an

9 *Adulteration* or *adulterated* applies to food products that contain harmful or deleterious substances or that fail to meet federal or state standards. Per the Federal Food, Drug, and Cosmetic Act (FFDCA), a food product can be deemed adulterated when, among other things, food is packaged or held under unsanitary conditions, food or ingredients are filthy or decomposed, or food contains any poisonous or deleterious substance. Reference: https://www.fda.gov/AnimalVeterinary/Products/AnimalFoodFeeds/ucm050223.htm. https://www.fda.gov/AnimalVeterinary/Products/AnimalFoodFeeds/ucm050223.htm.

10 Typically, acute exposure refers to a single exposure (not lasting longer than a day) or a short-term exposure (days or weeks) to a substance that causes severe biological harm or death. In contrast, chronic exposure to a hazardous substance occurs over an extended period (months or years), and the health effects are cumulative.

infected herd infects other herds, whether through livestock sales, fence line contact, shared equipment, or the movement of livestock or wildlife. This scenario applies to all contagions, not just waterborne contagions.

1.5.12 Available Information about the Protection of Human and Animal Health

In the water industry, the primary objective of research and policy for specific waterborne microorganisms and chemicals has been to protect public health—that is, to safeguard and improve the physical health of people and their communities. In the United States, for example, the National Primary Drinking Water Regulations (NPDWRs) are legally enforceable standards and treatment techniques used to limit the levels of specific contaminants that can adversely affect public health and that are known or anticipated to occur in water from public water systems (EPA, 2017, 2018).[11,12] The NPDWRs include Maximum Contaminant Levels (MCLs) for contaminants allowed in drinking water that is delivered in public water systems. MCL concentrations are set as close as possible to levels that are not anticipated to have public health consequences (Tchobanoglous et al., 2015).

Such standards are available for many known contaminants in water and wastewater, and new data from ongoing research continuously informs the state-of-science and ensuing guidance. Because of the emphasis on public health protection, research tends to focus on preventing adverse health effects in people. There is relatively little comparable guidance available in the United States, and only limited resources abroad, for livestock water quality (Shirley, 1974; Olkowski, 2009; CCME, 1993). Recognizing these limitations, the Panel assumed that:

- Chemical and microbial constituents that pose risks to human health may also pose risks to the health of livestock or the safety of animal products such as eggs and meat; however, this is a conservative assumption because many constituents that affect humans do not affect animals.
- Existing health objectives and guidance in the United States for chemical and microbial contaminants that are protective of human health also are protective of livestock health.

11 https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations

12 https://www.epa.gov/dwregdev/how-epa-regulates-drinking-water-contaminants#decide

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CHAPTER 2: DISINFECTED TERTIARY RECYCLED WATER IN CALIFORNIA

- History of recycled water production and use in California.
- Regulatory definition, uses, and applications of DTRW in California.
- Technologies used to produce DTRW.
- Animals and animal operations affected by recycled water in California.

The State of California has a long history of recycling wastewater for many purposes and has been a leader in establishing guidelines and regulations to ensure that it is used safely. In this chapter, the Panel provides a brief history of recycled water in California, background on how recycled water is produced from raw wastewater, and details about the regulatory requirements and production of DTRW. This chapter also includes information on current practices in California for the use of DTRW to meet agricultural needs, including livestock watering.

2.1. Recycled Water Use in California

Recycled wastewater has become an increasingly reliable source of supplemental water supplies in the United States. According to a recent survey by the US Government Accountability Office, at least 36 of 50 states were recycling water for beneficial uses in 2013 (GAO, 2014).

In California, recycled water has been used for more than a century to supplement and diversify limited water supplies. As early as 1890, California farmers began using untreated wastewater from municipal wastewater treatment plants (WWTPs) to irrigate crops and fields. Because acquiring sufficient water to support farms and ranches has always been a challenge, others took notice. Within a few decades, dozens of communities were using primary treated or partially treated wastewater to irrigate crops and landscapes (California's Recycled Water Task Force, 2003).

Although these recycled water sources had variable quality, they offered a viable solution to the ongoing problems of sustaining vegetation and bringing crops to market in drought-prone areas. California's first regulations for water reuse were adopted in 1918 and have been updated several times to include more types of recycled water applications, more advanced treatment processes and reliability requirements, and more protective water quality and monitoring requirements.

Building on early *ad hoc* applications of wastewater for beneficial purposes, California proceeded to develop large-scale planned reuse projects and, in 1912, the San Francisco Public Utilities Commission (SFPUC) began irrigating Golden Gate Park with minimally treated wastewater (Hyde, 1937). Although the surrounding community was supportive of efforts to conserve drinking water, there were concerns about the risks of using low-quality water in a public space. To address these concerns, SFPUC built the McQueen Treatment Plant in 1932 specifically to treat the recycled water used at Golden Gate Park (DWR, 2016). Since then, recycled water quality standards in California have been implemented and

improved to protect public health (California's Recycled Water Task Force, 2003). These standards are revisited regularly to ensure that best practices are prescribed in the regulations.

Ensuring sufficient water supplies to meet California's needs has been challenging for state lawmakers, especially given the large role of agriculture in the state's economy. The annual Crop Year Report indicates that agricultural sales in 2016 were approximately $45.3 billion, making California the top state in cash farm receipts (CDFA, 2016). The California Constitution[13] addresses California's need for water supplies in Article X, Section 2, added in 1976:

> Because of the conditions prevailing in this State the general welfare requires that the water resources of the State be put to beneficial use to the fullest extent of which they are capable, and that the waste or unreasonable use or unreasonable method of use of water be prevented, and that the conservation of such waters is to be exercised with a view to the reasonable and beneficial use thereof in the interest of the people and for the public welfare.

The State Water Board approved guidelines for regulating water reclamation in 1977.[14] Numerous other California statutes and laws have been developed as water supply challenges evolve. For example, the Porter-Cologne Act[15]—the law that governs the regulation of water quality in California—has been amended several times to address chronic water scarcity, contending that traditional water resources are no longer adequate to supply the state's steadily increasing population. The Act stated that, by 2000, California should produce at least 1 million acre feet (AF) of recycled wastewater annually. To plan for increased recycled water production, the State Water Board formed a Recycled Water Task Force to assess trends and determine future water recycling capabilities.[16] The Task Force has since identified more aggressive goals to increase California's production and use of recycled water and will likely continue, particularly for potable reuse projects that treat wastewater to drinking water standards and augment municipal water supplies.

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13 California Constitution, Article X, Water [Sections 1 - 7] (Article 10 added June 8, 1976, by Prop. 14) https://leginfo.legislature.ca.gov/faces/codes_displayText.xhtml?lawCode=CONS&division=&title=&part=&chapter=&article=X

14 California State Water Resources Control Board Resolution 77-1, Policy with Respect to Water Reclamation in California http://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/1977/rs77_001.pdf

15 Created in 1969, the Porter-Cologne Act (also known as California Water Code, Section 7) is the law in California that governs the regulation of water quality of surface water, groundwater, wetlands, and both point and nonpoint sources of pollution. It was established to protect both water quality and the beneficial uses of water. The State Water Resources Control Board and nine Regional Water Quality Control Boards resulted from this Act, which requires the adoption of water quality control plans that contain the guiding policies of water pollution management in California https://www.waterboards.ca.gov/laws_regulations/docs/portercologne.pdf

16 Detailed information from the State Water Board's periodic municipal wastewater recycling survey is available at: http://www.waterboards.ca.gov/water_issues/programs/grants_loans/water_recycling/munirec.shtml

2.2 Treatment Steps to Produce Recycled Water from Raw Wastewater

Modern WWTPs in California produce high-quality water through a process that transforms raw wastewater into recycled water. This process typically includes preliminary, primary, secondary, and tertiary wastewater treatment, as shown in **Figure 2-1**.

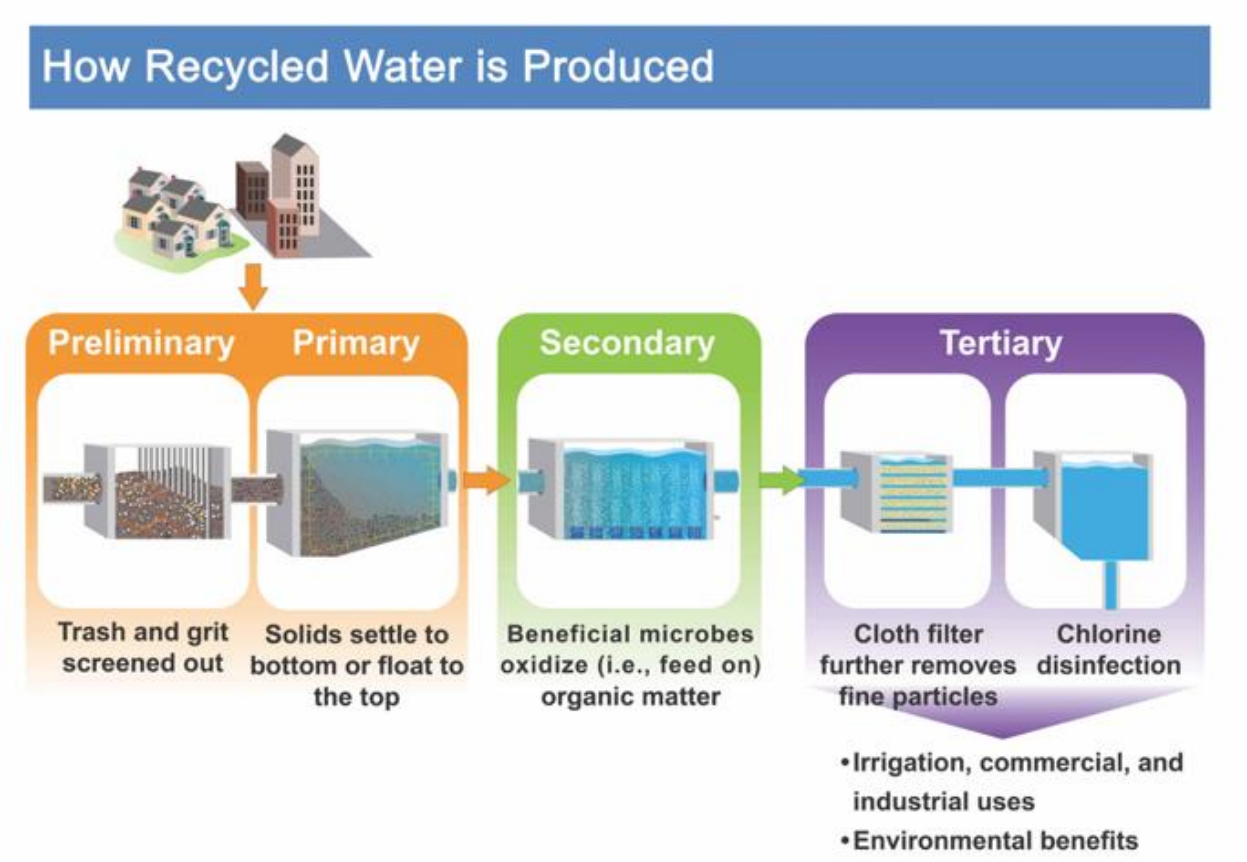

Figure 2-1. In California, Title 22 recycled water is produced through a series of treatment steps designed to remove solids, digest organic matter, and filter and inactivate pathogens. (Adapted from an image provided by the Los Angeles Department of Water and Power.)

Preliminary treatment involves screening out large solid materials and removing grit. Primary treatment targets heavier solids that settle to the bottom of a settling tank and scum that floats to the top, like grease. Secondary treatment promotes the microbial decomposition of organic material in water. During this process, beneficial microorganisms oxidize—or feed on—organic matter. Section 60301.650 of the California Water Code defines "oxidized" as "wastewater in which the organic matter has been stabilized, is nonputrescible, and contains dissolved oxygen." In California, some uses of secondary treated recycled water require disinfection, often with chlorine, to inactivate pathogens that may pose a risk to human health. Such uses include surface irrigation of cemeteries and freeway landscapes.

In California, tertiary treatment that includes both filtration and disinfection generally is the highest level of treatment applied to wastewater that is discharged to the environment for nonpotable reuse; the treatment criteria were developed to reduce the risks to human health. A number of different

treatment processes may be applied, and water managers must determine the most appropriate treatment that will produce water that meets the criteria for the intended end use. Such uses include safe discharge into a waterway; irrigation of food crops or landscapes; toilet and urinal flushing in approved buildings; industrial applications; other approved nonpotable uses; or additional treatment using advanced treatment technologies to reach drinking water standards.

Although tertiary treatment usually does not produce an end product that meets stringent federal and local regulations for drinking water, it does create high-quality water that can be used to offset the use of potable water for non-drinking purposes; therefore, tertiary treatment plays an important role in California's long-term strategy to maintain adequate water supplies. **Table 2-1** outlines the different levels of wastewater treatment.

Table 2-1: General Overview of the Levels of Wastewater Treatment

Treatment Level	Description
Preliminary	Removal of wastewater constituents and large particles (such as rags, sticks, floatables, grit, and grease) that may cause maintenance or operational problems with downstream treatment operations, processes, and ancillary systems.
Primary	Removal of a portion of suspended solids and associated organic matter from wastewater.
Advanced primary	Enhanced removal of suspended solids and organic matter from wastewater. Typically accomplished by chemical addition or filtration.
Secondary	Satisfactory reduction in biodegradable organic matter (in solution or suspension) and suspended solids. In Federal regulations, secondary treatment is defined as meeting minimum standards for biochemical oxygen demand (BOD) and total suspended solids (TSS) and meeting pH limits in effluents discharged from municipal WWTPs.
Secondary with nutrient reduction	Satisfactory reduction in biodegradable organics, suspended solids, and nutrients, such as nitrogen, phosphorus, or both nitrogen and phosphorus.
Tertiary	Further reduction of residual suspended solids (after secondary treatment), usually by granular media filtration, membranes, or microscreens. Often, disinfection is included in tertiary treatment as the final treatment process, although disinfection can be applied after any level of treatment before discharge. In some parts of the United States, nutrient reduction may be included under this treatment level based on discharge requirements to specific water bodies that need to be protected from excessive nutrients.
Advanced	Removal of dissolved, colloidal, and suspended materials that remain after secondary or tertiary treatment as required for various reuse applications.

Adapted from Tchobanoglous et al. (2014).

2.3 Regulation and Definition of Recycled Water in California

California's recycled water regulations are set forth in Title 22, Division 4, Chapter 3 of the California Code of Regulations. Water resources regulators, researchers, engineers, managers, and related stakeholders often refer to these regulations simply as "Title 22."

Early versions of the water reuse regulations refer to recycled water as "reclaimed," or some derivation of that term. In 1995, California's legislature acted to universally replace the term "reclaimed" in all California statutes with "recycled," which is now the correct legal term in California. Because this Panel was commissioned by the State Water Board, the term "recycled" and its derivatives are used throughout this report, except where the discussion focuses on other jurisdictions that use alternative terms.

Recycled water is defined in Section 13050(n) of the California Water Code as "water which, as a result of treatment of waste, is suitable for a direct beneficial use or a controlled use that would not otherwise occur and is therefore considered a valuable resource." The State Water Board permits several different recycled water qualities for non-potable uses; the criteria required for these uses is described in Title 22, Division 4, Chapter 3 of the California Code of Regulations, which was most recently amended in July 2016. The recycled water qualities include undisinfected secondary, disinfected secondary-23 (DS23), disinfected secondary-2.2 (DS2.2), and DTRW. Quality requirements are summarized in **Table 2-2.**

Table 2-2: Requirements for Disinfected Secondary and Disinfected Tertiary Recycled Water

Water Type	Total Coliform, 7-Day Median (per 100 mL)	Total Coliform, 30-Day, 1-Day Highest (per 100 mL)	Filtration Methods	Turbidity, 24-Hour Average (NTU)	Disinfection Requirements
DS23	<23	<240	Not required	Not required	Not specified, but must meet coliform criteria
DS2.2	2.2	23	Not required	Not required	Not specified, but must meet coliform criteria
DTRW	2.2	23*	Either (a) natural undisturbed soils or a bed of filter media; or, (b) microfiltration, ultrafiltration, nanofiltration, or reverse osmosis membrane	<2**	Either (a) minimum chlorine CT of 450 (mg·min)/L with a modal contact time of at least 90 minutes; or (b) an alternative process that removes 99.999-percent of MS2 phage or poliovirus in combination with the filtration process

Source: Titles 22 and 17 California Code of Regulations, State Board, Division of Drinking Water, Recycled Water Regulations, last updated July 16, 2015.

*Coliform bacteria cannot exceed an MPN of 23/100 mL in more than one sample in any 30-day period, and no sample can exceed an MPN of 240 total coliform/100 mL.

**For water filtered using soil or bed media, the 24-hour average turbidity may not exceed 2 Nephelometric Turbidity Units (NTU) and cannot exceed 5 NTU more than 5 percent of the time within a 24-hour period and may not exceed 10 NTU at any time. For membrane filtration, the average may not exceed 0.2 NTU more than 5 percent of the time within a 24-hour period and may not exceed 0.5 NTU at any time. Turbidity shall be recorded at intervals of no more than 1.2 hours over a 24-hour period. If the continuous turbidity meter and recorder fail, then grab sampling at a minimum frequency of 1.2 hours may be substituted for a period of up to 24 hours.

Notably, the State Water Board "…considers a properly filtered and disinfected recycled water meeting the turbidity performance and coliform requirements outlined in Title 22 to be essentially pathogen free" (State Water Board, 2014).

Regulatory Definitions from the California Code of Regulations

22 CCR § 60301.900: Undisinfected Secondary Recycled Water. This is oxidized wastewater. It is the lowest level of r treatment allowed under Title 22 for recycled water.

22 CCR § 60301.225: Disinfected Secondary-23 Recycled Water (DS23). DS23 is produced from secondary wastewater effluent that is oxidized and disinfected. Median concentration of total coliform bacteria in the disinfected effluent cannot exceed a most probable number (MPN) of 23 per 100 milliliters (mL) using the bacteriological results of the last 7 days for which analyses have been completed. Further, the number of total coliform bacteria cannot exceed an MPN of 240 per 100 mL in more than one sample in any 30-day period.

22 CCR § 60301.220: Disinfected Secondary-2.2 Recycled Water (DS2.2). DS2.2 also is produced from secondary wastewater effluent that is oxidized and disinfected; however, the median concentration of total coliform bacteria in the disinfected effluent cannot exceed an MPN of 2.2 per 100 mL using the bacteriological results of the last 7 days for which analyses have been completed. Further, the number of total coliform bacteria in DS2.2 cannot exceed an MPN of 23 per 100 mL in more than one sample in any 30-day period. This water is suitable for some types of irrigation and other uses where there is minimal human contact with the recycled water.

22 CCR § 60301.230: Disinfected Tertiary Recycled Water (DTRW). DTRW is the highest level of treatment required by Title 22 for nonpotable uses of recycled water. The secondary wastewater effluent is filtered according to the requirements of Title 22, Section 60301.320 and then disinfected so that it meets the following criteria:

> (a) The filtered wastewater has been disinfected by either: (1) A chlorine disinfection process following filtration that provides a CT value (the product of total chlorine residual and modal contact time measured at the same point) of not less than 450 milligram-minutes per liter at all times with a modal contact time of at least 90 minutes, based on peak dry weather design flow; or (2) a disinfection process that, when combined with the filtration process, has been demonstrated to inactivate and/or remove 5-log (99.999 percent) of the plaque forming units of F-specific bacteriophage MS2 or polio virus in the wastewater. Given that polio virus is no longer allowed to be used, a virus that is at least as resistant to disinfection as polio virus may be used for purposes of the demonstration.
>
> (b) The median concentration of total coliform bacteria measured in the disinfected effluent does not exceed an MPN of 2.2 per 100 mL using the bacteriological results of the last 7 days for which analyses have been completed and the number of total coliform bacteria does not exceed an MPN of 23 per 100 mL in more than one sample in any 30-day period. No sample shall exceed an MPN of 240 total coliform bacteria per 100 mL.
>
> For further clarification, the “filtered wastewater” used for DTRW is defined as follows:

22 CCR §60301.320: Filtered wastewater**.** Oxidized wastewater that meets the criteria in subsection (a) or (b):

(a) Has been coagulated and passed through natural undisturbed soils or a bed of filter media pursuant to the following:

(1) At a rate that does not exceed 5 gallons per minute per square foot of surface area in mono, dual or mixed media gravity, upflow or pressure filtration systems, or does not exceed 2 gallons per minute per square foot of surface area in traveling bridge automatic backwash filters; and

(2) So that the turbidity of the filtered wastewater does not exceed any of the following:

(A) An average of 2 NTU within a 24-hour period; (B) 5 NTU more than 5 percent of the time within a 24-hour period; and (C) 10 NTU at any time.

(b) Has been passed through a microfiltration, ultrafiltration, nanofiltration, or reverse osmosis membrane so that the turbidity of the filtered wastewater does not exceed any of the following:

(1) 0.2 NTU more than 5 percent of the time within a 24-hour period; and (2) 0.5 NTU at any time.

2.4 Technologies Used to Produce Disinfected Tertiary Recycled Water

Following secondary treatment, many technologies can be used to produce DTRW. The best method for a given site must be determined based on the quality of the source water, intended end use of the water, and resources available at the WWTP. In some cases, it may be appropriate to apply multiple treatment processes to achieve the required water quality specifications.

The State Water Board has approved the following to meet the requirements of Title 22:

1. Filtration technologies:
    - Granular media filters.
    - Natural undisturbed soils.
    - Cloth filters.
    - Non-granular media filters.
    - Microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and/or reverse osmosis (RO) membranes.
    - Other filters and non-polymeric membrane filters.
2. Disinfection methods:
    - Chloramine disinfection.
    - Free chlorine disinfection.
    - Ozone/peroxide.
    - Pasteurization.
    - Ultraviolet (UV) irradiation.

2.5 Agricultural Uses and Applications of Recycled Water in California

Over the past 50 years, the State Water Board has expanded the approved uses of recycled water beyond irrigating landscapes and agricultural land used for grazing and fodder crops. Now, Title 22 specifies 43 approved uses for recycled water, including the irrigation of edible crops with DTRW.

Historically, primary effluent was used to irrigate crops, but that practice is no longer allowed because of the high bacteria content of the water (Pettygrove, 2004). Currently, undisinfected secondary effluent, which is oxidized wastewater, is approved only for irrigating forage crops and vineyards where the water does not come in contact with the edible portion of the crop; food crops that must undergo commercial pathogen-destroying processing before being consumed by people; and non-food-bearing trees, nursery stock, and sod farms provided there is no irrigation within 14 days before harvesting or access by the general public. These restrictions are designed to reduce the risk of human infection.

Research has demonstrated that recycled water is safe to irrigate salad vegetables and strawberries; an 11-year analysis by a California water agency found no viruses on samples of crops grown with recycled water, and naturally occurring bacteria were equivalent to control samples (Sheikh et al., 1990). In addition, a quantitative risk assessment published in 2012 concluded that California's current agricultural water recycling regulations do not measurably increase public health risk and that modifying the standards to make them more restrictive will not measurably improve public health. (Cooper, 2012).

The most recent California Municipal Wastewater Recycling Survey found that 714,000 acre-feet per year (AFY) of recycled water was put to beneficial reuse in 2015, and 31 percent (220,000 AF) was used for agricultural irrigation. Given that the State Water Board's Recycled Water Policy aims to increase the use of recycled water above 2002 amounts by at least 1 million AFY by 2020, and by 2 million AFY by 2030, the opportunities to use recycled water for agricultural irrigation are likely to increase. However, it is worth noting that agriculture consumes a shrinking portion of total recycled water in California: before 2001, approximately 60 percent of recycled water was used for agricultural irrigation and, by the 2009 survey, that number decreased to 37 percent. This decrease might be attributed to demand by other approved uses, as well as the recognition of the value of recycled water.

2.6 Animals and Animal Operations Affected by Recycled Water in California

California currently allows the use of recycled water for agricultural practices that affect animals. In Title 22 CCR Section 60304, in which the regulations for the use of recycled water for irrigation are outlined, disinfected secondary-23 recycled water, which is a less stringent water quality criterion than DTRW, can be used to irrigate pasture for livestock that produce milk for human consumption.

A lower standard of recycled water, such as undisinfected secondary, is approved to irrigate fodder, fiber, and pasture for animals that do not produce milk for human consumption, as shown in **Table 2-3**.

Table 2-3: Approved Recycled Water Uses in California that Affect Animals

Animal Use	Title 22 Recycled Water Quality (Minimum)
Pasture for dairy animals	Secondary disinfected (23)
Pasture for non-dairy animals	Secondary (undisinfected)
Fodder and fiber crops and pasture for non-dairy animals	Secondary (undisinfected)
Seed crops not eaten by people	Secondary (undisinfected)
Publicly accessible impoundments at fish hatcheries	Secondary disinfected (2.2)

Source: Titles 22 and 17 California Code of Regulations, State Board, Division of Drinking Water, Recycled Water Regulations, Last updated July 16, 2015.

Although current regulations do not specify that recycled water can be used for livestock watering, there is anecdotal evidence that it has and continues to occur across the State. A 1996 report by Black & Veatch noted that recycled water has been used since the early 1980s at the California Polytechnic Institute at Pomona for livestock watering and for wash down and irrigating feed pastures. Further, "…it was reported that Cal Poly has not experienced any health problems with animals" (B&V, 1996). More recently, a reporter for the *Press Democrat* quoted a dairy rancher who had been "filling drinking troughs with treated wastewater for years." The rancher restricted its use to young cows that are not producing milk, based on his understanding of the regulation (Moore, 2014). In addition, a fact sheet distributed by the University of California Cooperative Extension Sustainable Irrigation Project lists "livestock drinking water" as a legal use of DTRW.[17] Repeated efforts to contact the author of the fact sheet were unsuccessful; therefore, it is unknown if the C Cooperative Extension service is aware of other California livestock producers who are using DTWR for this purpose.

2.7 Summary of Use of Disinfected Tertiary Recycled Water Use in California

In summary, DTRW is California's highest required standard of treated wastewater that is intended for non-potable use. DTRW is suitable for a number of beneficial uses that may offset the use of drinking water sources like groundwater and imported water for agricultural irrigation, which accounts for 80 percent of consumptive water use in the State. Recycled water has become increasingly important to communities seeking to develop local, drought-proof water supplies, and its use will continue to increase as required by state mandates to conserve potable water and increase the use of recycled water.

17 Available at the University of California Extension website at http://cesonoma.ucdavis.edu/files/27168.pdf

2.8 References

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CHAPTER 3: PANEL GUIDANCE AND RESOURCES FOR WATERING NON-DAIRY LIVESTOCK WITH DTRW

- Relevant guidance and regulations for using DTRW to water non-dairy livestock in the United States and abroad.
- Other resources that the Panel found useful and relevant.

This chapter summarizes the data and resources that were available to the Panel. Because the practice of giving DTRW to non-dairy livestock is not common or officially recognized, information was limited. **Section 3.1** focuses on relevant federal guidance, and **Section 3.2** addresses relevant state regulations (other than California); for information on California's regulations for recycled water, see **Chapter 2**. **Section 3.3** focuses on relevant guidance from Australia, Canada, and the European Union, and **Section 3.4** contains descriptions of data and information from other resources, such as technical reports, that were useful to the Panel.

3.1 Relevant Federal Guidance and Regulations

The Panel gathered information from the USDA, EPA, FDA, and other federal entities that either address or could contribute to an understanding of the water quality and health issues associated with watering non-dairy livestock with recycled water.

3.1.1 Animal Welfare Act

The USDA enforces the Animal Welfare Act, which was passed by Congress in 1966 to ensure the humane care and treatment of animals that are:

1. Bred for commercial sale, such as dogs and cats;
2. Sold over the internet;
3. Exhibited to the public, such as zoo animals;
4. Used in biomedical research; or
5. Transported commercially (USDA, 2017).

Among its requirements, the Act provides specific instructions to provide "adequate potable water" to animals under its purview, though the term potable water is not defined further in the Act.

Notably, the requirements set forth in the Act do not extend to livestock. The only water quality criteria specifically listed in the Act are bacterial standards for marine mammals.

3.1.2 US Environmental Protection Agency's 2012 Guidelines for Water Reuse

Although the federal government has no authority over water recycling regulations, the EPA provides an overview of the regulatory frameworks in States that practice water reuse. The EPA's *Guidelines for*

Water Reuse is updated periodically (EPA, 2012). The 2012 *Guidelines* noted that recycled water is generally not used for livestock watering in the United States, although unregulated *de facto* reuse by municipal water treatment plants does occur. *De facto* reuse commonly occurs when a community draws water from a river or reservoir that receives treated municipal wastewater from communities upstream. To address this issue, EPA (2012) has the following guidance:

> *EPA 2012 Guidelines, Section 3.2.5, Reclaimed Water for Livestock Watering*
>
> Generally, in the United States, reclaimed water is not utilized for direct consumption by livestock; however, *de facto* reuse often occurs. In this case, a table is provided as a guide to acceptable water quality for livestock consumption. It should be noted that the information in the table was developed from FAO 29 Water Quality in Agriculture, with more recent updates from Raisbeck et al. (2011) for molybdenum, sodium, and sulfate (FAO, 1985). These values are based on amounts of constituents normally found in surface and groundwater and are not necessarily the limits of animal tolerance. Additional sources of these substances may need to be considered along with drinking water, such as additional animal intake of these substances through feedstuffs. If concerns persist about safety for livestock, the local land-grant university should be consulted for additional information.

The EPA guidelines for concentrations of substances in livestock drinking water are in **Table 3-1**.

Table 3-1. EPA 2012 Guidelines for Concentrations of Substances in Livestock Drinking Water[a]

Constituent (Symbol)	Concentration (mg/L)
Aluminum (Al)	5.0
Arsenic (As)	0.2
Beryllium (Be)b	0.1
Boron (B)	5.0
Cadmium (Cd)	0.05
Chromium (Cr)	1.0
Cobalt (Co)	1.0
Copper (Cu)	0.5
Fluoride (F)	2.0
Iron (Fe)	Not needed
Lead (Pb)c	0.1
Manganese (Mn)d	0.05
Mercury (Hg)	0.01
Molybdenum (Mo)	0.3
Nitrate + Nitrite (NO3-N + NO2-N)	100
Nitrite (NO2-N)	10.0
Selenium (Se)	0.05
Sodium (Na)	1000e
Sulfate (as SO4)	1000f
Vanadium (V)	0.10
Zinc (Zn)	24.0

[a] Adapted from FAO (1985) with updates for Mo, Na, and SO_4 from Raisbeck et al. (2011).

[b] Insufficient data for livestock; value for marine aquatic life is used.

[c] Lead is accumulative, and problems may begin at a threshold value of 0.05 milligrams per liter (mg/L).

[d] Insufficient data for livestock; value for human drinking water used.

[e] Short-term exposure (days/weeks) can be up to 4,000 mg/L, assuming normal feedstuff Na concentrations.

[f] Short-term exposure (days/weeks) can be up to 1.8 mg/L, assuming normal feedstuff SO_4 concentrations.

3.1.3 Regulation of Chemical Residues in Meat and Eggs

The Panel had to determine if using DTRW for livestock watering would negatively affect livestock or human health. An important consideration is whether chemicals in DTRW might accumulate in meat or eggs from livestock that drink DTRW, and whether people consuming meat and eggs might experience negative health outcomes from those residues. Fundamental to this assessment was an understanding of federal regulations governing chemical residues in meat and animal products.

Several federal agencies regulate chemical residues in meat, and the relationship between the specific chemical residues and the organization that has enforcement authority is complex (PEW, 2016). A brief description of the process of developing and enforcing regulatory thresholds is explained in the rest of this section.

The US Food and Drug Administration Center for Veterinary Medicine (FDA CVM) establishes tolerances for animal drugs and feed additives that are purposefully given to livestock for therapeutic or production purposes. A tolerance is defined as the maximum allowable concentration of a marker residue, such as the parent compound or a metabolite that can be reliably quantified, in edible tissues. The FDA CVM assumes that all tissue residues, the "total residue" composed of the parent compound plus metabolites, may have toxicological consequences unless proven otherwise.

Safe concentrations of total residue are calculated based on:

1. Toxicological studies that establish no-effect concentrations[18] of the chemical;
2. Acceptable daily intake (ADI)[19],[20] of the chemical, incorporating safety factors that are based on the extensiveness and quality of the available toxicological data; and
3. Consumption estimates[21] for various edible tissues, such as meat, liver, kidneys, or fat.

Safe tissue concentrations are calculated using the following formula:

Safe tissue concentration = (ADI × Human Body Weight)/(Food Consumption Value)

The concentration of a marker residue is in a known relationship to the concentration of total residue (FDA CVM, 2016); therefore, a tolerance is the concentration of marker residue in an edible tissue when the total residue is at a safe concentration. Residue depletion studies are used to establish the length of time necessary for a marker residue to deplete to meet tolerance values.

The FDA then uses the data gathered from residue depletion studies to establish a withdrawal period, which is the minimum time required between the animal's last exposure to a drug and its slaughter date to ensure that the marker residue does not exceed the tolerance. In addition to safety factors incorporated into the calculation of the ADI, the withdrawal period is conservatively calculated to ensure with 95 percent certainty that marker residues in 99 percent of a population of treated animals do not exceed the tolerance concentrations (FDA CVM, 2016). Details on the FDA CVM's calculation of withdrawal periods are in **Appendix 3A.**

In some cases, the responsibility for setting a tolerance is determined by the route of exposure. For example, normally pesticides tolerances in food animals are established by the EPA, because animals are often exposed pesticide indirectly via feed. However, if the animal is exposed to the pesticide directly (i.e., it is applied topically or given orally for a systemic effect) then FDA CVM rather than EPA will establish the tolerance (FDA, 2017). To further complicate the process, the EPA and FDA CVM do not necessarily use the same safety factors or consumption values in calculating the ADI or tolerances.

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18 No observable effect levels (NOEL), No observable adverse effect levels (NOAEL) or a benchmark dose (BMD).

19 Acceptable Daily Intake (ADI): A measure of the amount of a specific substance (originally applied for a food additive, later also for a residue of a veterinary drug or pesticide) in food or drinking water that can be ingested (orally) on a daily basis over a lifetime without an appreciable health risk.

20 ADI in mg/kg body weight= (NOEL, NOAEL, or BMD) ÷ Safety Factor.

21 FDA CVM human food consumption estimates: Muscle, 300 grams per day (g/d); Liver, 100 g/d; Kidney, 50 g/d; Fat, 50 g/d; Eggs, 100 g/d.

However, both agencies use similar principles for establishing no-effect levels during toxicity testing, the ADI of a chemical, and the use of safety factors in assessing risks.

Once a tolerance is established, another agency, the USDA Food Safety and Inspection Service (FSIS), is charged with monitoring residues in eggs and meat at slaughter facilities in the United States. The FDA is also responsible for residue surveillance in other foods, such as milk, fruits, vegetables, and nuts. For meat animals, monitoring typically consists of a statistically designed, pre-planned random sampling program and inspector-generated samples. Inspector-generated samples are removed at slaughter from, "…suspect individual animals, suspect populations of animals, and animals condemned for specific pathologies" (FSIS, 2017a). Condemned animals are believed to be of relatively higher risk to contain violative residues[22] than other animals in the herd or at the slaughter facility. Targeted sampling also occurs for animals that come from production facilities with a history of residue violations. Sampling plans and the statistical rationale for random sampling are described by the FSIS in its annual publication, *United States National Residue Program for Meat, Poultry, and Egg Products*, commonly referred to as the "Blue Book."

The FSIS measures specific chemicals in animal tissues because they are:

1. Approved animal drugs or feed additives with established regulatory tolerances;
2. Heavy metals of human health concern;
3. Non-approved animal drugs or feed additives having the potential for or a history of off-label use or abuse; or
4. Pesticides of potential human health concern.

In selecting pesticides for monitoring, the FSIS sets priorities in six categories (FSIS, 2017a). Within each category, a rank (1 to 6, with 1 being low and 6 being high) is assigned depending on a chemical's characteristics for probability of exposure and toxicity:

1. Usage (S): Amount of chemical distributed per year.
2. Bioavailability (B): A gross measure of absorption and bioaccumulation potential based on the octanol/water partition coefficient (log K_{ow}).[23]
3. Frequency (F): The frequency with which a given compound was detected in meat by the FSIS in past sampling periods. The frequency is adjusted (L) for compounds that were not analytes in past FSIS chemical screens. Chemicals not considered in past assays are assigned adjustment (L) values of 2. Chemicals regularly screened for but not detected are assigned L values of -1.

22 A violative residue occurs when the concentration of a chemical residue in a tissue or food matrix exceeds a threshold established by a regulatory body. Such thresholds may be termed tolerances, maximum residue levels, or action levels depending upon the regulatory agency and nature of the chemical residue.

23 K_{ow} = Ratio of a chemical's concentration in the octanol phase to its concentration in the aqueous phase; it is used as a surrogate measure for a chemical's potential to accumulate in animal tissues.

4. Health Effects (H): The relative estimated toxicity based on chronic population-adjusted doses (cPAD) estimated by EPA risk assessments.
5. Carcinogenic Potential (C): Based on the EPA's *Chemicals Evaluated for Carcinogenic Potential* (EPA, 2006).

The ranking of each chemical is based on the relative score derived by:

Relative Public Health Risk Score = [(S+B+F)/3] x [(H+C)/2] + L

Using this ranking system, the FSIS has evaluated more than 475 chemicals that it will consider for inclusion in the National Residue Program (FSIS, 2017a). The FSIS will include compounds that rank high in its multi-residue screening method after analytical methods for those analytes are validated.

Punitive measures for animal producers who repeatedly violate residue requirements can be severe. Farming and/or ranching establishments with more than one residue violation in the previous 12-month period are named in the "Residue Repeat Violator List" (RRVL). This list is issued weekly by the FSIS (FSIS, 2017b) and is available to market animal buyers (usually meat packing facilities) who bear the economic losses of slaughtering animals that contain violative residues. Being named on the RRVL makes it difficult for a cattle rancher to find a terminal market and gives a substantial economic disincentive for selling chemically adulterated animals.

3.1.4 Regulation of Chemical Residues in Drinking Water for Livestock

Primary standards for trace-level chemicals in drinking water do not exist in the United States for livestock as they do for humans. The Panel could not find state-regulated standards for trace level contaminants that might occur in DTRW, specifically for livestock. Canada, however, has an established risk-assessment process to evaluate the safety of chemicals in livestock water, which is described in **Section 3.3.2.**

3.1.5 Regulation of Chemical Residues in Drinking Water for Humans

In the absence of livestock water quality standards for most chemicals of emerging concern (CECs), the Panel relied on water quality standards for human drinking water (see **Chapter 5**). The Panel reasoned that water quality standards protective of human health would be protective of livestock health. A complete review of regulations for chemical residues in human drinking water is beyond the scope of the Panel's charge, per AB 2071. The topic was, however, thoroughly discussed by Anderson et al. (2010) in a report commissioned by the State Water Board titled, "Monitoring Strategies for Chemicals of Emerging Concern (CECs) in Recycled Water." Since the publication of Anderson et al. (2010), the EPA reviewed the Candidate Contaminant List 3 (CCL 3) and issued the Candidate Contaminant List 4 (CCL 4) in 2016.[24] These updated lists are discussed in **Chapter 5,** as are predicted no-effect concentrations (PNECs) in human drinking water for CCL 3 and CCL 4 chemicals. Other human drinking water guidelines

24 The chemical and microbial contaminants in the Contaminant Candidate List (CCL) currently are not subject to any proposed or promulgated national primary drinking water regulations but are known or anticipated to occur in public water systems. Contaminants on the CCL may require future regulation under the Safe Drinking Water Act (SDWA). The US Environmental Protection Agency (EPA announced the Final CCL 4 on November 17, 2016, which includes 97 chemicals or chemical groups and 12 microbial contaminants. The list includes, among others, chemicals used in commerce, pesticides, biological toxins, disinfection byproducts, pharmaceuticals, and waterborne pathogens (EPA, 2017).

used by Anderson, et al., (2010) were also consulted by the Panel, including California Drinking Water Notification Levels, such as:

1. Health-based advisory levels established in California for chemicals in drinking water that lack the PNECs calculated by Schwab (2005).
2. Australian 2008 drinking water guidelines (DWG).[25]
3. American Water Works Association[26] (2008) drinking water equivalent levels (DWEL).
4. Provisional Guideline Values (PGV) calculated by Schriks et al. (2009).
5. Lowest guideline values calculated by Cotruvo et al. (2010).

The derivation of these guideline values is reproduced from Anderson et al. (2010) and is provided in **Appendix 3B**.

3.2 Relevant Regulations and State-Level Guidance

In the United States, some states and territories have developed their own regulations for water recycling criteria. Currently, Arizona, Colorado, Hawaii, Minnesota, Oklahoma, and Virginia either regulate or plan to regulate the use of recycled water for livestock watering or livestock feed consumption. Relevant regulations in California were described in **Chapter 2**.

3.2.1 Arizona

The Arizona Department of Environmental Quality has established water quality standards and allowable uses for reclaimed water in the Arizona Administrative Code under Title 18 Environmental Quality – Chapter 11 Water Quality Standards (AZSOS, 2017). Under Article 3, livestock watering applications, as well as pasture irrigation for livestock, are divided between dairy animals (Class B) and non-dairy animals (Class C). Class B requires fecal coliform organisms in four of the last seven water samples to be less than 200/100 mL with a single maximum fecal count of less than 800/100 mL. Class C reclaimed water requires that fecal coliform organisms in four of the last seven water samples to be less than 1,000/100 mL, and the single maximum fecal count is less than 4,000/100 mL. Standards for trace-level chemicals are not established. Regulations do not specify which animal species may be given the recycled water beyond the dairy/non-dairy distinction. **Table 3-2** outlines the minimum treatment required and allowable agricultural uses of reclaimed water in the State of Arizona.

25 From Tables 4.4, A1, A2, A8a, and A8b in Environment Protection and Heritage Council et al. (2008). *Australian Guidelines for Water Recycling. Augmentation of Drinking Water Supplies*. May 2008.

26 From Tables 9.1 and 9.2 in Snyder et al. (2008). *Toxicological Relevance of EDCs and Pharmaceuticals in Drinking Water*. AWWA Research Foundation. 484 pp.

Table 3-2. Reclaimed Water Treatment and Allowable Agricultural Uses in Arizona

Requirements	Class B Reclaimed Water	Class C Reclaimed Water
Minimum Treatment	Secondary treatment with disinfection	Secondary treatment with/without disinfection
Microbial Indicator Limit	Fecal coliforms: (a) Less than 200/100 mL in last four of seven samples; (b) 800/100 mL (maximum)	Fecal coliforms: (a) Less than 1,000/100 mL in last four of seven samples; (b) 4,000/100 mL (maximum)
Turbidity Limit NTU	Not specified	Not specified
Allowable Uses	Dairy animals, livestock/cattle watering, and pasture irrigation	Non-dairy animals, livestock/cattle watering, and pasture irrigation

mL = Milliliter. NTU = Nephelometric turbidity unit. Information compiled from AZSOS (2017).

3.2.2 Colorado

The Colorado Department of Public Health and Environment (CDPHE) Water Quality Control Commission (WQCC) regulates recycled water (referred to as "reclaimed water") for non-potable uses under Regulation 84 Reclaimed Domestic Wastewater Control (5 CCR 1002-84) (CO SOS, 2017). The purpose of the regulation is "…to establish requirements, prohibitions, standards, and concentration limits for the use of reclaimed water to protect public health and the environment while encouraging the use of reclaimed water" (CWQCC, 2013). Denver Water is proposing that four new uses be added to Regulation 84, including the following two uses related to the consumption of recycled water by livestock:

1. Livestock wash down and watering, and the irrigation of crops for human consumption and other uses within community gardens and other resident-controlled, unrestricted locations.
2. Irrigation of crops for human consumption in commercial agriculture applications.

To facilitate this process, CDPHE and Denver Water initiated a series of meetings in 2017 to support stakeholder discussions and develop revision recommendations. **Table 3-3** outlines the minimum treatment required and allowable agricultural uses of three categories of reclaimed water in Colorado. Standards for trace-level chemicals have not been proposed.

Table 3-3. Reclaimed Water Treatment and Allowable Agricultural Uses in Colorado

Requirements	Category 1 Reclaimed Water	Category 2 Reclaimed Water	Category 3 Reclaimed Water
Minimum Treatment	Secondary treatment with disinfection	Secondary treatment with filtration and disinfection	Secondary treatment with filtration and disinfection
Microbial Indicator Limit	*E. coli*: (a) 126/100 mL monthly geo mean; (b) 235/100 mL (maximum)	*E. coli*: (a) 126/100 mL monthly geo mean; (b) 235/100 mL (maximum)	*E. coli*: (a) None in 75 percent samples; (b) 126/100 mL (maximum)
Turbidity Limit NTU	Not specified	<3-month average and maximum 5 in <5 percent samples in a month	<3-month average and maximum 5 in <5-percent samples in a month
Allowable Uses	Agricultural irrigation (non-food crop irrigation and silviculture); commercial (zoo operations)	Agricultural irrigation (Category 1 uses)	Agricultural irrigation (Category 1 uses) *Proposed livestock watering*

mL = Milliliter. NTU = Nephelometric turbidity unit. Information compiled from CO SOS (2017).

3.2.3 Hawaii

In Hawaii, water recycling is overseen by the Wastewater Branch of the Hawaii State Department of Health. Hawaii regulates three grades of recycled water: R-1, R-2, and R-3. The highest grade, R-1, has "undergone oxidation, filtration and disinfection" and can be used as "drinking water for livestock, and poultry with the exception of dairy animals that produce milk for human consumption," and for "agricultural cleaning to wash down animals such as cattle, livestock, animal pens and housing" (HI DOH, 2016a). The requirements for R-1 water are provided in Chapter 62 (Wastewater Systems) of Title 11 of the Department of Health Administrative Rules (HI DOH, 2016b). **Table 3-4** outlines the treatment required and the allowable uses of reclaimed water for farm animals in Hawaii. Standards for trace-level chemicals are not established.

Table 3-4. Reclaimed Water Treatment and Allowable Agricultural Uses in Hawaii

Requirements	R-1 Recycled Water
Minimum Treatment	Oxidation, filtration, and disinfection[a]
Microbial Indicator Limit	Fecal coliforms: Median density in disinfected effluent limited to 2.2/100 mL using results from last 7 days; Density in more than one sample in any 30-day period limited to 23/100 mL; Density in any one sample limited to 200/100 mL.
Turbidity Limit	Filtration using sand or granular media, cloth, or other synthetic media: average of 2 NTU within 24-hour period; 5 NTU more than 5 percent of the time within a 24-hour period; 10 NTU at any time. Filtration using membrane filtration: 0.2 NTU more than 5 percent of the time within a 24-hour period; 0.5 NTU at any time.
Allowable Uses	Non-dairy cattle and poultry; agricultural cleaning to wash down cattle, livestock, animal pens and housing.

mL = Milliliter. NTU = Nephelometric turbidity unit. Information compiled from AZSOS (2017).

[a] The chlorine disinfection process shall have a CT (the product of total chlorine residual and modal contact time measured at the same point) of not less than 450 milligram-minutes per liter at all times with a modal CT of at least 90 minutes based on a peak dry flow. The non-chlorine

disinfection process must demonstrate the inactivation and removal of 99.999 percent of the plaque-forming units of the F-specific bacteriophage MS2, or polio virus, in the wastewater.

3.2.4 Minnesota

In 2009, an estimated 32 Minnesota cities reused treated effluent for irrigation of agricultural crops, grassland, or forests. Since 1992, the Minnesota Pollution Control Agency (MPCA) has used the State of California Regulations as guidance for the permitting of wastewater reuse. The required treatment is based on the type of reuse and uses established criteria for total coliform bacteria counts (MPCA, 2010). Currently, the State of Minnesota is evaluating water quality criteria for livestock and wildlife uses, referring to their Class4B surface water standard as a possible starting point. Standards for trace-level chemicals are not established. **Table 3-5** outlines the minimum treatment required and allowable agricultural uses of recycled water in Minnesota.

Table 3-5. Recycled Water Treatment and Allowable Agricultural Uses in Minnesota

Requirements	Description
Minimum Treatment	Disinfected tertiary, secondary, filtration, disinfection
Microbial Indicator Limit	2.2 MPN/100 mL Total Coliform bacteria
Turbidity Limit NTU	2 NTU daily average; 10 NTU daily maximum turbidity
Allowable Uses	Food crops where recycled water contacts the edible portion of the crop, including root crops

mL = Milliliter. NTU = Nephelometric turbidity unit. Information compiled from Minnesota PCA (2010).

3.2.5 Oklahoma

The Oklahoma Department of Environmental Quality (OK DEQ) Water Quality Division regulates Oklahoma's public water supplies and municipal and industrial treatment requirements. Water reuse requirements are specified in Title 252, Chapter 656 *Water Pollution Control Facility Construction Standards*, Subchapter 27 *Wastewater Reuse* (OK DEQ, 2012). Range cattle watering is an allowed reclaimed water use for Category 2, and pasture irrigation is allowed for Categories 3 and 5 with unrestricted and restricted access, respectively. Additional requirements for water reuse systems are specified in Title 252, Chapter 627 *Operation and Maintenance of Water Reuse Systems*.

Table 3-6 outlines the minimum treatment required and allowable agricultural uses of reclaimed water in Oklahoma. Standards for trace-level chemicals are not established.

Table 3-6. Reclaimed Water Treatment and Allowable Agricultural Uses in Oklahoma

Requirements	Category 2 Reclaimed Water
Minimum Treatment	Secondary treatment with filtration and disinfection
Microbial Indicator Limit	Adenovirus Type 15: 5-$\log_{10}$ removal *Salmonella typhimurium*: 5-$\log_{10}$ removal *Giardia lamblia*: 3-$\log_{10}$ removal
Turbidity Limit NTU	Not specified
Allowable Uses	Dairy animals, non-dairy animals, livestock/range cattle watering

mL = Milliliter. NTU = Nephelometric turbidity unit. Information compiled from OK DEQ (2012).

3.2.6 Virginia

Virginia's State Water Control Board currently regulates two reclaimed water quality requirements, for the allowable reclaimed water uses listed in Chapter 740 on "Water Reclamation and Reuse Regulation" in the Virginia Administrate Code (VAC) (VA GA, 2017). Non-dairy livestock watering is an allowable use for Level 2 reclaimed water (Level 1 disinfection requirements apply to dairy livestock). Level 2 allowable uses also include irrigating pasture for foraging livestock. Standards for trace-level chemicals are not established. **Table 3-7** outlines the minimum treatment required and allowable agricultural uses of reclaimed water in Virginia.

Table 3-7 Reclaimed Water Treatment and Allowable Agricultural Uses in Virginia

Requirements	Level 1 Reclaimed Water	Level 2 Reclaimed Water
Minimum Treatment	Secondary treatment with filtration and higher-level disinfection	Secondary treatment with standard disinfection
Microbial Indicator Limit	Fecal coliforms: (a) 14/100 mL (monthly geo mean), (b) 49/100 mL (maximum); *E. coli*: (a) 11/100 mL (monthly geo mean), (b) 35/100 mL (maximum); Enterococci: (a) 11/100 mL (monthly geo mean), (b) 24/100 mL (maximum)	Fecal coliforms: (a) 200/100 mL (monthly geo mean), (b) 800/100 mL (maximum); *E. coli*: (a) 126/100 mL (monthly geo mean), (b) 235/100 mL (maximum); Enterococci: (a) 35/100 mL (monthly geo mean), (b) 104/100 mL (maximum)
Turbidity Limit NTU	(a) 2 NTU (24-hour average); (b) 5 NTU (maximum)	Not specified
Allowable Uses	Milking livestock/cattle watering and pasture irrigation	Non-milking livestock/cattle watering and pasture irrigation

mL = Milliliter. NTU = Nephelometric turbidity unit. Information compiled from LIS (2017).

3.3 Relevant Guidance and Regulations Abroad

Australia and Canada have published regulations that include criteria for using recycled water for livestock drinking water. In addition, the European Commission (EC) proposes that the European Union (EU) adopt regulations for water reuse by the end of 2017.

3.3.1 Australia

The National Guidelines for Water Recycling are an authoritative reference for the supply, use, and regulation of recycled water in Australia. These guidelines, which are risk-based for microbial pathogens, were developed for human exposures and also address animal exposure routes, primarily through the irrigation of pasture, fodder and crop irrigation, livestock drinking water, and shed or stockyard wash down (NRMMC et al., 2006). The main concerns for livestock exposure include:

1. Abattoir (slaughterhouse) or livestock sale yard waste as a potential source of the bacterial pathogen *Mycobacterium paratuberculosis.* This pathogen causes Johne's disease, a fatal wasting disease that is a risk to the cattle industry in some Australian states.
2. The eggs (ova) of helminthic parasites *Taenia saginata* (beef tapeworm) and *Taenia solium* (pork tapeworm) may be present in wastewater and other water sources that are contaminated with human and animal excreta. Because *Taenia solium* has a pig-human

lifecycle, it can cause disease in people; consequently, reclaimed wastewater is not allowed for pig production purposes in Australia (EPA Victoria, 2003).[27]

Although the Australian wastewater recycling guidelines note that "many human pathogens, including human enteric viruses, are not of significant concern for livestock health," one limitation of this conclusion is that "virtually no dose-response models are available for infection in animals." The guidelines address this limitation by recommending recycled water treatment processes and water quality objectives along with the use of on-site controls to manage potential hazards in the livestock industry, as shown in **Table 3-8** (NRMMC et al., 2006). Standards for trace-level chemicals were not provided.

Table 3-8. Treatment Processes and Additional Controls for the Use of Recycled Water in Association with Livestock (Excluding Pigs)[a] in Australia

Indicative Treatment Processes	On-site Preventive Measures	Water Quality Objectives
Livestock drinking water		
Secondary treatment with helminth reduction (>25 days of lagoon detention or an equivalent filtration process) and disinfection, or Primary treatment with >50 days of lagoon detention or disinfection	Recycled water not to be used for consumption by cattle under 12 months of age if the source of water contains animal waste from a slaughterhouse or sale yard.	Soluble BOD_5 <20 mg/L SS <30 mg/L Disinfectant residual (e.g., minimum chlorine residual) or UV dose[b] *E. coli* <100 per 100 mL
Dairy shed wash down		
Secondary treatment with helminth reduction (>25 days of lagoon detention or an equivalent filtration process) and disinfection, or Primary treatment with >50 days of lagoon detention and disinfection	Recycled water not to be used for wash down of milking machinery (unless specifically considered in human health risk assessment).	Soluble BOD_5 <20 mg/L SS <30 mg/L Disinfectant residual (e.g., minimum chlorine residual) or UV dose[b] *E. coli* <100 per 100 mL
Pasture or fodder crop irrigation including hay, silage and commercial fodder production. **Limited withholding period**		
Secondary treatment with helminth reduction (>25 days of lagoon detention or an equivalent filtration process) and disinfection, or Primary treatment with >50 days of lagoon detention and disinfection	Exclude lactating dairy cattle from pasture for 4 hours or until pasture is dry. Fodder is dried or ensiled, not for human consumption. Public in vicinity of site: No public access during irrigation. 25- to 30-meter buffer distance to nearest public access point. Spray drift control by using low-throw sprinklers, micro sprinklers, drippers, part circle sprinklers (180° inward throw), vegetation screening, or anemometer switching.	Soluble BOD_5 <20 mg/L SS <30 mg/L Disinfectant residual (e.g., minimum chlorine residual) or UV dose[b] *E. coli* <100 per 100 mL

27 Per the Environmental Protection Authority Victoria: "Pigs must not be fed or exposed to pasture or fodder produced or irrigated with reclaimed water sourced from human sewage. Also pigs should not be allowed to drink reclaimed water sourced from human wastes. This restriction reflects that *Taenia solium* (a helminth with pig-human lifecycle) can potentially cause a severe disease in humans and needs to be stopped from establishing a lifecycle in Australia" (EPA Victoria, 2003).

Pasture or fodder crop irrigation (including hay, silage and commercial fodder production). **With withholding period**		
Secondary treatment with helminth reduction (>25 days of lagoon detention or an equivalent filtration process) and disinfection, or Primary treatment with >50 days of lagoon detention and disinfection	Exclude grazing animals for 5 days after irrigation. Fodder dried or ensiled (not for human consumption). Public in vicinity of site: No public access during irrigation. 25- to 30-meter buffer distance to nearest public access point. Spray drift control (e.g. through low-throw sprinklers, micro sprinklers, drippers, part circle sprinklers [180° inward throw], vegetation screening, or anemometer switching).	• Soluble BOD_5 <20 mg/L • SS < 30 mg/L • *E. coli* <100 per 100 mL

a Source: Table 3.9 from NRMMC et al. (2006).

b The aim is to demonstrate the reliability of disinfection and the ability to consistently achieve microbial quality.

BOD_5 = Biochemical oxygen demand over 5 days. SS =Suspended solid. UV = Ultraviolet. mL = Milliliter. mg/L = Milligram per liter.

3.3.2 Canada

In contrast to all other nations, Canada has an established, formal risk-assessment process to evaluate the safety of trace-level chemicals in water given to livestock. This process is described in detail by the Canadian Council of Ministers of the Environment in a 1999 protocol, *Water Quality Guidelines for the Protection of Agriculture*, which was used to establish the safety of chemicals in water used for agricultural irrigation and as livestock drinking water (CCME, 1999).

The livestock protocol is a science-based risk assessment that hinges on the availability of toxicological data of priority compounds (typically, pesticides) in livestock. Datasets for mammalian livestock species are defined as:

1. A minimum of three studies on three or more mammalian species, that include at least two livestock species including a ruminant species.
2. At least two long-term studies that include endpoints such as growth, reproduction, production variables, and developmental metrics. Preferably, these studies will include the full lifecycle of the species.
3. A minimum of one study that investigates the bioaccumulation of a chemical in at least one livestock species. Other data may be considered if bioaccumulation data on a livestock species are not available.

Similar studies are required for avian species, except that a minimum of two toxicology studies are required, and one must be a long-term study in a domestic avian livestock species. The guidelines recognize, and account for, the fact that multiple long-term toxicology studies may not be available for livestock and provides for the use of interim guidelines when full datasets are not available.

The Canadian guidelines are based on tolerable daily intakes (TDI), defined as “an estimate in milligrams per kilogram body weight per day of a substance that is not anticipated to result in any adverse health effects following chronic exposure to a population of livestock species, including sensitive subgroups.”

(CCME, 1999) Guideline values are derived using the methods shown in **Appendix 3C**. The Panel used a number of these guideline values in its assessment of the safety of chemicals that might occur in DTRW (see **Chapter 5**).

3.3.3 European Commission of the European Union

The European Commission (EC) is developing guidance for future legislation to regulate water reuse across the EU. Currently, several EU countries have issued their own standards for the use of reclaimed water. Although the EC has not suggested that livestock watering should be an approved use, it does recommend restrictions on irrigating fodder crops with recycled water based on the risks to animal species that are most vulnerable to certain pathogens.

Table 3-9 outlines permitted applications related to livestock production in the EU; in general, these applications involve the irrigation of fodder crops or pastures for meat- and milk-producing animals, and do not include livestock watering as a permitted application of reclaimed water. Only microbial parameters are listed in this table; physical-chemical parameters such as turbidity, pH, electrical conductivity, chlorides, nitrogen, and phosphorus, among others, were not included for the sake of brevity. Parameters for trace-level chemical constituents, if available, were not provided in the source material (Alcalde Sanz and Gawlik, 2014).

Table 3-9. Water Reuse for Livestock Operations in Countries of the European Union

Country	Required Microbial Monitoring	Livestock-Related Reuse Allowed
Cyprus	E. coli, Helminth eggs	Irrigation of fodder crops
France	E. coli, Fecal enterococci, Sulfite-reducing bacteria, F-specific bacteriophages	Irrigation of fodder crops Irrigation of pastures for milk or meat-producing animals
Greece	E. coli, Total coliforms	Irrigation of fodder crops Irrigation of pastures for milk or meat-producing animals Water process and cleaning in the food industry
Italy	E. coli, Salmonella sp.	Irrigation of fodder crops Irrigation of pastures for milk or meat-producing animals Water process and cleaning in the food industry
Portugal	E. coli, Helminth eggs	Irrigation of fodder crops Irrigation of pastures for milk or meat producing animals
Spain	E. coli, Legionella spp., Salmonella sp., Helminth eggs	Water process and cleaning in the food industry

Adapted from Alcalde Sanz and Gawlik (2014).

Table 3-10 is an overview of draft minimum preventative measures under development for the application of reclaimed water for agricultural uses in the EU and for livestock production, but not for livestock watering specifically (Alcalde Sanz and Gawlik, 2017).

Table 3-10. Draft Minimum Preventative Measures for the Specific Application of Reclaimed Water for Agricultural Uses, in Development by the European Union

Reclaimed Water Quality	Technology Target	Specific Additional Preventive Measures
Class A	Secondary treatment, filtration, and disinfection, and advanced water treatments	Pigs must not be exposed to fodder irrigated with reclaimed water unless there is sufficient data to indicate the risks for the specific case can be managed.
Class B[a]	Secondary treatment and disinfection	Prohibit harvesting of wet irrigated or fallen produce. Exclude lactating dairy cattle from pasture until pasture is dry. Fodder has to be dried or ensiled before packaging. Pigs must not be exposed to fodder irrigated with reclaimed water unless there is sufficient data to indicate the risks for the specific case can be managed.
Class C[a]	Secondary treatment, and disinfection	Prohibit harvesting of wet irrigated or fallen produce. Exclude grazing animals from pasture for 5 days after last irrigation. Fodder has to be dried or ensiled before packaging. Pigs must not be exposed to fodder irrigated with reclaimed water unless there is sufficient data to indicate the risks for the specific case can be managed.

[a] Class B water quality criterion is ≤100 CFU/100 mL of *E. Coli* whereas Class C is ≤1,000 CFU/100 mL.

Sources: Alcalde Sanz and Gawlik (2017); Miehe (2017).

3.4 Other Relevant Resources

The Panel consulted many sources for background information, data, and recommendations that are relevant to the use of DTRW for livestock watering.[28] Several are identified in the next section, listed by publication date.

3.4.1 Monitoring Strategies for Chemicals of Emerging Concern in Recycled Water

The State Water Control Board convened a Science Advisory Panel (SAP) in 2009 to develop monitoring strategies for CECs in recycled water (Anderson et al., 2010). Given the general lack of toxicity data for livestock species considered in this report, the drinking water benchmarks provided in Anderson et al. (2010) were consulted by the current Panel, which assumed that benchmarks developed for human drinking water would be conservative when applied to livestock species.

The SAP's primary charge was to provide guidance for developing monitoring programs that assess potential threats from CECs from various water recycling practices, including indirect potable reuse that uses surface spreading and subsurface drinking water aquifer replenishment and irrigation of urban landscapes. The desired outcomes were to develop a conceptual framework for:

1. Determining which CECs to monitor.
2. Applying the framework to identify chemicals that should be monitored.

28 See Section 1.1 of Chapter 1 for a list of resources recommended by the State Water Resources Control Board based on guidance provided in Section 13521.1 of the California Water Code.

3. Developing a sampling design and approach for interpreting CEC monitoring results.
4. Developing priorities for improving monitoring programs and the interpretation of CEC data moving forward.

The SAP focused on potential human health risks from identified CECs and used conservative benchmarks due to limited data on measured environmental concentrations (MECs) of CECs. The SAP also acknowledged the potential regional differences in recycled water quality and facility operation. Chapter 7 of the SAP's Final Report was the most relevant to the Panel's consideration of chemical risks to livestock and to humans through the consumption of meat and eggs.

Due to the large number of CECs in recycled water, the SAP developed a screening process to prioritize chemicals for ongoing monitoring programs. The prioritizing process was straightforward. MECs or predicted environmental concentrations (PECs) of chemicals at the point of monitoring (POM) were compared to a triggering benchmark called a monitoring trigger level (MTL). The process for deriving an MTL was outlined by the SAP. If the MEC ÷ MTL was greater than1, the chemical was placed on a priority monitoring list. Values less than 1 were not considered to be of concern, although if a suitable indicator or surrogate chemical could be identified, that indicator was placed on the priority monitoring list. The MTLs were intended to be sufficiently low so that chemicals of potential human health concern could be identified and included in a monitoring program.

The SAP provided drinking water benchmarks from seven sources (see Appendix J in Anderson et al., 2010), which helped the Panel evaluate potential human and livestock health risks of DTRW. The sources included peer-reviewed literature and benchmarks developed by three regulatory agencies: the EPA, the California Department of Public Health, and the Australian Environmental and Heritage Council. The number of benchmarks available for an individual CEC varied, and one or more drinking water benchmarks were provided for 418 potential CECs. The SAP believed that the provided MTLs were protective and appropriate for use in a monitoring program.

The SAP evaluated toxicological information extensively to assess the risk to people from CECs in recycled waters under the listed conditions of use. One important conclusion was that the epidemiological studies, mice studies, bioassays, and risk assessments provided evidence that appropriately treated water may be used safely to supplement potable drinking water supplies. However, the SAP also emphasized the importance of monitoring the recycled water to assure its continued safety.

The SAP's report also: (1) recommended screening approaches for identifying and quantifying known, known unknowns, and unknown chemicals in treated water at the POM, and (2) discussed the use of both instrumental and bioanalytical approaches. The current Panel used the information in the SAP report to help develop recommendations for ongoing monitoring programs that protect livestock and human health.

3.4.2 Source, Fate, and Transport of Endocrine Disruptors, Pharmaceuticals, and Personal Care Products in Drinking Water Sources in California

In 2010, NWRI released a report that evaluated the presence and fate of CECs, such as pesticides, pharmaceuticals, and components of personal care products, in three major drinking water sources for

more than 25 million people in Southern California. The three water sources included the State Water Project, Colorado River, and Santa Ana River (Guo et al., 2010).

The report, titled *Source, Fate, and Transport of Endocrine Disruptors, Pharmaceuticals, and Personal Care Products in Drinking Water Sources in California*, was prepared by researchers at the Metropolitan Water District of Southern California and the Orange County Water District, who conducted a two-year, $300,000 study to better understand the presence and effects of CECs found at extremely low levels in water supplies. The research team analyzed the presence of 49 CECs, which were selected based on common occurrence, the ability to either be reduced or to remain stable in the natural environment, and other criteria. The CECs selected for analysis included flame retardants such as TCEP, detergent metabolites such as 4-n-Nonylphenol, antibiotics such as ciprofloxacin, anticonvulsants such as carbamazepine, hormones such as testosterone, and herbicides such as atrazine.

The research team collected water samples from April 2008 through April 2009 from the three water sources at 32 locations, ranging from upstream of the City of Sacramento to Orange County, California, and from locations along the Colorado River in Arizona and Nevada. Each of these water sources receives treated wastewater discharges and agricultural runoff and supports recreation and other activities that can contribute CECs. Altogether, the research team detected 27 CECs out of the 49 CECs analyzed in water samples from the three water sources; the remaining 22 CECs were not detected in any of the sources. The CECs detected were found at the nanograms per liter (ng/L) range.

Notably, the ability to detect a compound does not necessarily translate to human or animal health concerns. To date, no adverse health impacts have been documented from exposure to the extremely low concentrations of CECs found in water supplies, according to the study. The current Panel used data from the 2010 report by Guo et al. to better understand the frequency of detections and concentrations of CECs in recycled waters and in waterways that receive DTRW.

3.4.3 Review of California's Water Recycling Criteria for Agricultural Irrigation: Recommendations of an NWRI Independent Advisory Panel

In 2012, an NWRI Independent Advisory Panel (IAP) submitted a final report to the California Department of Public Health (CDPH) that addressed whether recycled water produced in conformance with California's Water Recycling Criteria was sufficiently protective of public health for agricultural food crop irrigation. The report was written in response to increased interest in expanding the amount of recycled water used in California for agricultural purposes (Cooper et al., 2012). It specifically addressed the risk of exposure and infection from waterborne pathogens, such as *Cryptosporidium* and pathogenic *E. coli*, due to the irrigation of a wide variety of food crops using recycled water. The different recycled water qualities considered by the NWRI IAP included: (1) undisinfected secondary recycled water; (2) disinfected secondary recycled water (2.2 MPN/100 mL); and (3) DTRW.

The report was prepared by nine experts in microbiology and virology, quantitative microbial risk assessment, public health infectious diseases and epidemiology, water reuse, food safety and hazard analysis, agricultural practices, irrigation management, waterborne infectious agents, and water and wastewater treatment. Collectively, they represented "over 150 years of combined experience investigating water reuse and potential public health issues" (Cooper et al., 2012).

Key issues addressed by the NWRI IAP included:

1. Characterizing "safe" recycled water for use in irrigation.
2. Making appropriate assumptions about acceptable risk to public health.
3. Studying the relevance of current criteria for reducing viruses and using chlorine disinfection.
4. Evaluating the need for multiple barrier treatment processes to remove microorganisms.
5. Using turbidity as a valid parameter to assess the performance of treatment processes. Turbidity generally is measured in DTRW after filtration or membrane processes that precede disinfection.
6. Examining standards used to define secondary wastewater treatment, which is generally interpreted to include biological treatment processes to remove contaminants and/or bacteria.
7. Using total coliform bacteria to assess the effectiveness of disinfection in reducing microorganisms.
8. Understanding the ability of crops to take in viruses through their roots, leaves, and other points of entry, and any associated risks to public health.

In the report, the NWRI IAP responded to each issue and suggested refinements to the Water Recycling Criteria for the State of California. Among the conclusions in the report, the NWRI IAP stated that "…current agricultural practices that are consistent with the (Water Recycling Criteria) do not measurably increase public health risk, and that modifying the standards to make them more restrictive will not measurably improve public health."

The report provided a scientific basis for the NWRI IAP's conclusion that irrigating food crops with recycled water did not pose an increased public health risk.

3.4.4 Risks and Benefits of Tertiary Sewage Effluent as Drinking Water for Livestock in California: Opinions of an Expert Panel

As described in **Chapter 1**, the 2014 WRAC Expert Panel—consisting of 23 members from a variety of institutions—was charged with developing a position paper on whether the use of DTRW as drinking water for livestock was: (1) safe for livestock (cattle, swine, and poultry) and the human consumers of products from such animals, and (2) whether livestock producers would use the water (Atwill et al., 2014). The guiding questions included:

1. Does the use of DTRW represent an elevated or unacceptable animal or human health risk relative to other available livestock water sources?
2. If an elevated or unacceptable risk was identified, what measures could be taken to reduce the risk to acceptable levels?
3. If insufficient information is available to make a determination, what information is needed?

The 2014 WRAC Expert Panel considered three categories of chemicals: hormones, antibiotics, and other chemicals, including metals, pesticides, and disinfection byproducts.

Of the various hormones considered, the 2014 WRAC Panel report said that estrogens were the greatest concern and provided data to show that the direct risk varied depending on the animal population receiving the water. The report also indicated that long-term use beyond the traditional lifespan of the animal population is necessary for an adverse effect to occur.

For antibiotics, the 2014 WRAC Panel identified two risks: (1) potential for residues to occur in milk, and (2) potential for the development of antibiotic-resistant bacteria. The 2014 WRAC Panel thought the dangers to livestock from metals, pesticides, and disinfection byproducts were low, but little data was available; therefore, the ability to make accurate and meaningful assessments was limited.

The 2014 WRAC Expert Panel concluded that the risks from pathogens or chemicals to livestock were minimal in almost all cases, and that the benefit of using the water for livestock during an emergency drought situation outweighed any risk. Unfortunately, the evidence provided in the report was limited and, as noted in the report, the conclusions "…reflect the collective perspective of scientists and veterinarians who had valuable input into the discussion based upon their expertise and experience." There was no consideration of direct or indirect exposures or risk to human health through eating meat, eggs, or milk.

The 2014 WRAC Expert Panel suggested that a monitoring program be implemented to determine hormone concentrations in DTRW, and that it was important to continually reassess risk. However, it should be noted that risk correlations between hormone concentrations and exposure are not currently developed.

3.4.5 Expert Panel Final Report: Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse

Direct potable reuse (DPR) is defined in the California Water Code as the "…planned introduction of recycled water either directly into a public water system, as defined in Section 116275 of the Health and Safety Code, or into a raw water supply immediately upstream of a water treatment plant."

In 2010, the California State Legislature signed SB 918 into law, which required the State Water Board to report to the Legislature by December 31, 2016, on the feasibility of developing uniform water quality criteria for DPR. The legislative mandate was detailed in Sections 13560-13569 of the California Water Code. Per the mandate, 12 water industry experts were appointed to an independent, third-party Expert Panel to give advice and guidance to the State Water Board on the following topics:

1. Advise the State Water Board on public health issues and scientific and technical matters regarding the feasibility of developing uniform statewide water recycling criteria for DPR.
2. Assess what, if any, additional research is needed to establish uniform regulatory criteria for DPR and recommend an approach for accomplishing the additional needed research in a timely manner.

Administered by NWRI on behalf of the State Water Board, the DPR Expert Panel prepared a report titled *Evaluation of the Feasibility of Developing Uniform Water Recycling Criteria for Direct Potable Reuse*, based on the most current research and activities around DPR in the United States.

The DPR Expert Panel reported that "…microbial contaminants (including bacteria, viruses, and protozoa parasites) were acknowledged as the most critical constituents to regulate in recycled water due to the potential impacts to human health resulting from short-term exposure (most effects arise shortly after exposure, although chronic sequelae of acute infection are known to occur)." Among the large number of chemicals that can be present in recycled water, "…some were of concern due to their potential adverse health effects associated with both short-term and long-term exposures" (Olivieri et al., 2016).

The DPR Expert Panel concluded that it is feasible for the State of California to develop and implement uniform water recycling criteria for DPR that would incorporate a level of public health protection as good as or better than what is currently provided by conventional drinking water supplies, indirect potable reuse (IPR) systems using groundwater replenishment, and proposed IPR projects that include surface water augmentation (Olivieri et al, 2016). In summary, this report provided a useful approach to monitoring recycled water for pathogens and chemicals to protect public health.

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PART 2: EVALUATING POTENTIAL RISKS

CHAPTER 4: POTENTIAL RISKS TO PEOPLE AND NON-DAIRY LIVESTOCK—WATERBORNE PATHOGENS

- Waterborne pathogens of concern for people and non-dairy livestock.
- General considerations related to waterborne pathogens and their removal by treatment.
- Treatment process efficacy for pathogen inactivation or removal.
- Livestock regulatory perspectives on pathogenic microorganisms and recycled water.
- Relevance of DTRW on the health of people and non-dairy livestock.
- The Panel recommends the State Water Board to adopt best management practices including Title 22 compliant ultraviolet light disinfection to ensure public and animal health.

4.1 Introduction

Municipal wastewater treatment systems receive input from homes, businesses, hospitals, government institutions, and industrial facilities. While the quality of municipal wastewater is unique to each community, all untreated wastewater is expected to contain pathogenic microorganisms (Olivieri et al., 2016). This chapter assesses the potential health risks to both human and non-dairy livestock posed by pathogens that may be present in untreated municipal wastewater and emphasizes the importance of treating water to reduce these risks. Pathogens of concern include viruses, bacteria, protozoa, helminths (parasitic worms) ova, and fungi. The Panel focused on waterborne pathogens because these organisms pose the most immediate and significant health risk to people and animals.

Background is provided in **Section 4.2** on waterborne pathogens of potential concern to human and livestock health. A detailed discussion on DTRW production processes used to remove pathogens follows in **Section 4.3**, and **Section 4.4** addresses health risks associated with using DTRW as a water supply for non-dairy livestock. **Section 4.5** includes additional considerations and **Section 4.6** presents the Panel's conclusions and recommendations.

4.2 Waterborne Pathogenic Microorganisms of Concern

Pathogens represent the greatest threat to the safety of water supplies because of their acute effects on animal and human health. According to WHO (2017c), "…most waterborne pathogens are introduced into drinking-water supplies through human or animal feces, do not grow in water, and initiate infection in the gastrointestinal tract following ingestion." Notably, waterborne pathogens also may be transmitted by food, contact between people and animals (person-to-person, animal-to-animal, and animal-to-human), and through contact with contaminated objects and surfaces. Therefore, water may be a pathway of exposure for some waterborne infectious diseases (Olivieri et al., 2016).

The Panel focused on waterborne pathogens that represent potential risks to both livestock and human health and that could potentially disrupt food production. In addition, the Panel considered scenarios in which DTRW could serve as a potential source of contagion if there are pathogens in the water supply. The Panel assumed the following exposure pathways for people:

- Eating food products such as meat, eggs, and sausages made from livestock that ingested DTRW.
- Transmitting communicable diseases from infected livestock to people, particularly workers at livestock facilities that use DTRW, and through animal feces, saliva, blood, and other means. This pathway would be of concern only if the disease originated from a microbial organism in the water supply.

Likewise, the Panel assumed the following exposure pathways for non-dairy livestock:

- Ingesting DTRW as a primary drinking water source.
- Incidentally ingesting or inhaling DTRW used at the livestock facility for other purposes, including washing, dust abatement, fire suppression, irrigation, and other non-potable uses.

4.2.1 Overview of Waterborne Pathogens and Their Treatment

The Panel evaluated five classes of waterborne pathogens relevant to DTRW: viruses, bacteria, protozoans, helminths, and parasitic fungi. Some pathogens are zoonotic—that is, they transmit infections that normally exist in animals but that can also infect and cause disease in people. **Table 4-1** gives a brief description of each pathogen class and persistence through the water treatment cycle.

Table 4-1. Description and Persistence of Pathogens in DTRW

Pathogen Class	Description	Persistence in Disinfected Tertiary Recycled Water
Viruses	Small (20 to 80 nm) infectious agents that replicate only inside the living cells of other organisms. Viruses can infect animals, plants, and microorganisms such as bacteria, and are transmitted through body fluids, inhalation, ingestion, and other routes. Enteric viruses primarily infect the intestinal tract when consumed in food and water contaminated with viruses of fecal origin. In general, human enteric viruses are host-specific and do not infect other animals, but there are a few exceptions (e.g., Hepatitis E).	Although unable to replicate outside the host, viruses can persist in treated water due to their small size and colloidal interactions, which hinder physical removal, and resistance to certain disinfection processes (e.g., UV resistance of adenovirus). According to Myrmel et al. (2006), viruses are resilient to environmental stresses such as biotic and sunlight effects in aquatic ecosystems but can be physically removed or inactivated by processes commonly used in the production of DTRW such as membrane filtration, chemical and UV disinfection, and ozone oxidation.
Bacteria	Ubiquitous, single-celled microbes typically 100 times larger than viruses. Most waterborne bacteria replicate in the gastrointestinal tract (enteric bacteria) and are excreted in feces (WHO, 2017c). Some enteric bacteria are zoonotic: *Campylobacter jejuni* is endemic in livestock and seldom causes disease in animals, but can be transmitted from animals to people through poultry contaminated with feces during slaughter (WHO, 2017d). In the United States, enteric bacteria represented approximately 10 percent of all waterborne disease outbreaks and 20 percent of enteric disease cases from 2011 to 2012 (Beer et al., 2015).	Enteric bacteria are more susceptible to environmental stresses than viruses are, and their larger size makes them easier to remove physically by granular media and/or membrane filtration processes commonly used in the production of DTRWs. Generally, pathogenic bacteria are susceptible to disinfection processes commonly used to treat water and wastewater (e.g., free chlorine, chloramine, UV, and ozone).

Pathogen Class	Description	Persistence in Disinfected Tertiary Recycled Water
Parasitic Protozoa	Single-celled organisms that can divide only within a host organism. Larger in size than bacteria, parasitic protozoa are among the most common causes of gastrointestinal disease in people and animals (WHO, 2017c). Parasitic protozoa that live in the intestines (enteric protozoa) are typically transmitted by a fecal-oral route, such as through contaminated food or water or person-to-person contact (CDC, 2016a). *Giardia lamblia* and *Cryptosporidium hominis* produce cysts and oocysts, which are hardy structures that allow them to survive in the environment for months.	Parasitic protozoa cysts and oocysts typically are present in secondary-treated wastewater effluent and can be resistant to some chemical disinfectants, particularly chlorination. The cysts or oocysts of *Giardia*, *Cyclospora*, *Cryptosporidium*, and other protozoa (e.g., Toxoplasma) can be removed using filtration and are effectively inactivated with disinfectants such as ozone and UV (Hijnen and Medema, 2010; de Lima Isaac et al., 2014).
Helminths	Parasitic worms such as nematodes, tapeworms, and flukes, that persist in excreta as ova (eggs) – in untreated wastewater. Helminths are among the most common causes of disease in developing regions (WHO, 2017c). These large, multicellular organisms are visible to the naked eye in their adult stages, and exposure is mainly through ingestion of helminth eggs (CDC, 2016). Helminth eggs infect people and animals through the following pathways: (1) the ingestion of food crops or water contaminated with untreated wastewater or sewage sludge, (2) direct contact with untreated wastewater or feces, and (3) ingestion of contaminated meat or fish (Jiménez-Cisneros, nd). Few species of helminth exchange between animals and people. Helminth infections can lead to malnutrition, anemia, liver disease, and intestinal discomfort in both people and animals.	Helminth egg concentrations in untreated wastewater typically are much higher in developing countries than developed countries; concentrations range from <1 to >1,000 per liter of raw wastewater, depending on the source (Gyawali, 2018). Numerous studies have quantified the removal of helminth ova through wastewater treatment processes (WHO, 2003, 2006; Trussell et al., 2013). Typical helminth ova measure between 20 and 100 µm and behave like suspended solids. They are largely removed through wastewater treatment processes. Removal efficiencies of 90 and 99.99 percent have been observed for primary and secondary treatment, respectively (Gyawali, 2018). Helminth eggs are large and usually found in low numbers in untreated wastewater, and many are resistant to chlorine, but they are effectively removed by filtration: 2- to 3-$\log_{10}$ removal for dual media filters and >6 $\log_{10}$ removal for membrane filters have been routinely documented.
Fungi	Of concern are infectious parasitic fungi, particularly microsporidia that produce resistant spores of varying sizes. At least 15 species have been identified as human pathogens, and 6 species may naturally infect wild and domestic animals (CDC, 2017c).	Fungi have been detected in filtered tertiary treated waste waters (Dowd et al., 1998). They show similar resistance to disinfectants as *Cryptosporidium* and *Giardia* (John et al., 2005). Physical removal by conventional drinking water treatment is similar to MS-2, but fungi are more resistant to disinfection (Gerba et al., 2003). The same species infects both people and animals: For example, *Enterocytozoon bieneusi* infects both people and pigs (Stentiford et al., 2016). Both water and food borne transmission have been documented.

4.2.2 Pathogens of Concern

The Panel focused on specific waterborne pathogens that pose potential risks to both livestock and human health and could potentially disrupt food production. The primary pathogens of concern include the viruses, bacteria, parasitic protozoa, and fungi listed in **Table 4-2**. A discussion of the rationale for excluding helminths and prions from this evaluation follows the table. Antibiotic-resistant bacteria (ARB) and antibiotic-resistant genes (ARG) are discussed separately in **Appendix 4A,** and more detailed descriptions of the pathogens listed below are provided in **Appendices 4B and 4C.**

Table 4-2. Primary Waterborne Pathogens of Concern to Both Animal and Human Health as Related to the Use of DTRW for Livestock Watering

Pathogen	Health Concern	Rationale for Inclusion
Virus		
Hepatitis E virus	Human: Infectious hepatitis. Animal: Infections in swine are usually asymptomatic; cause of Avian hepatitis-E-virus infection of poultry.	Hepatitis E virus type 3 can infect both people and swine, while other strains affect poultry. HEV has been detected in wastewater in Spain, India, and Switzerland (Park et al., 2016; Meng, 2005).
Bacteria		
Salmonella enterica	Human: salmonellosis and gastroenteritis. Animal: Gastroenteritis, septicemia, abortion, and sometimes death in livestock likely due to dehydration.	One of the most frequently documented waterborne bacterial pathogens causing acute gastrointestinal illness (CDC, 2018). Also, one of the most frequently reported causes of foodborne illness; the USDA requires testing of *Salmonella* in meat and poultry (FSIS 2017 and 2018). Indicator to assess the removal and inactivation of other bacterial pathogens through water and wastewater treatment.
Mycobacteria spp.	Human: Respiratory illness (hypersensitivity pneumonitis). Animal: Bovine tuberculosis causes weakness, weight loss, fever, hacking cough, diarrhea, prominent lymph nodes, and death in cattle. Non-tuberculous mycobacteria (NTM) cause gastrointestinal disease in swine and respiratory disease in poultry.	Infection of cattle and other ruminants causes costly regulatory culling due to false positive on tuberculosis testing. Bovine tuberculosis (*M. bovis)* is a zoonotic pathogen that must be monitored at the interface of humans, livestock, and wildlife.
Campylobacter spp.	Human: Gastroenteritis, reactive arthritis, Guillain-Barré syndrome. Animal: Enteritis in swine and ruminants, abortion in ruminants, mastitis in cattle.	One of the most frequently documented waterborne bacterial pathogens causing acute gastrointestinal illness (CDC, 2017a). It also is one of the most frequently reported causes of foodborne illness; the USDA requires testing of *Campylobacter* in poultry (FSIS 2017, 2018). Can serve as an indicator to assess the removal and inactivation of other bacterial pathogens through water and wastewater treatment.
Clostridium perfringens spores	Human: Gastroenteritis, necrotizing enteritis. Animal: Enteritis and hemorrhagic enterotoxaemia in cattle, sheep, goats, and horses.	Bacterial spores common to wastewater; some produce toxins and are resistant to disinfectants. Often used as an indicator for the removal of viral and parasitic protozoa pathogens. Humans are the most important reservoir for Clostridial food poisoning (Acha and Szyfres, 1991).

Pathogen	Health Concern	Rationale for Inclusion
Protozoa		
Giardia lamblia (*Giardia intestinalis*)	Human: Giardiasis (gastroenteritis). Animal: Cause of diarrhea in young animals.	One of two parasitic protozoa pathogens regulated under the EPA's Surface Water Treatment Rules, with high level of disease burden in the United States (Scallan et al., 2011). Young and adult cattle commonly are infected with this pathogen.
Cryptosporidium parvum	Human: Cryptosporidiosis (gastroenteritis). Animal: Cause of diarrhea and death due to dehydration in young animals.	One of two parasitic protozoan pathogens regulated under the EPA's Surface Water Treatment Rules, with high level of disease burden in the United States (Scallan et al., 2011). Calves commonly are infected with this pathogen.
Neospora caninum	Human: Unknown. Animal: Abortion in cattle.	May cause cattle abortions, as reported in California. Infectious oocysts could be present in wastewater contaminated by dog feces disposed of in municipal sewage. There is no evidence of zoonosis for this protozoan, and people are not a source of the infection for livestock.
Toxoplasmosa gondii	Human: Miscarriage and birth defects. Animal: Abortion in sheep and goats.	A less common cause of abortion in sheep and goats but may cause miscarriage and birth defects in people. Infectious oocysts could be present in wastewater contaminated by cat feces disposed of in municipal sewage. This zoonotic infection is passed to people directly from cat feces and indirectly through consumption of raw or undercooked meat from swine, sheep, or goats infected via food or water contaminated with cat feces.
Fungi		
Enterocytozoon bieneusi	Human: Intestinal microsporidiosis and diarrhea in immunocompromised persons. Animal: Pigs often asymptomatic. In cattle, clinical signs include fever, inappetence, diarrhea, ptyalism, reduced milk production, oral ulcers and mucosal lesions (Baker, 1995).	Most common species of microsporidia infecting people and animals, including pigs and cattle. Recent studies in Brazil, the Czech Republic, and China revealed its presence in commercial livestock including pigs, calves, heifers, and beef cattle. The genotypes detected overlap with those previously reported in people, and therefore a risk of zoonotic transmission (da Silva Fiurza et al., 2016; Sak et al., 2010; Stentiford et al., 2016).

4.3 Pathogen Detection, Monitoring, and Removal

Given the importance of pathogen control for public health protection, much work has gone into quantifying pathogen concentrations in raw wastewater and the treatment processes to reduce pathogens. This section discusses pathogen detection, the limitations of direct pathogen measurement, and the use of indicator and surrogate monitoring frameworks to assess treatment process

performance. Finally, this section describes the pathogen reduction performance of common wastewater treatment processes.

4.3.1 Monitoring Recycled Water Production Processes

Pathogen and indicator monitoring are used to determine if treatment process performance complies with public health criteria. Risk-based thresholds are often used to define adequate levels of public health protection. Typically, potable drinking water treatment must reduce the annual risk of infection to one in 10,000 people per year (EPA, 1989). Thus, municipal drinking water sources—which are currently allowed for livestock watering—should carry a risk of one infection for every 10,000 people per year. The target concentration that corresponds to this level of risk depends on a number of factors, including the route and degree of exposure and the risk of becoming infected by a given pathogen.

Pathogen detection methods include visual identification via microscopy, standard culture methods, biochemical (phenotypic) assays, molecular methods such as PCR, immunological assays, and biosensors. Verifying target pathogen concentrations in treated effluent is challenging because monitoring technologies are limited, expensive, labor-intensive, and insufficiently sensitive; furthermore, the small datasets these technologies generate do not represent the true variation in treatment performance. For example, directly monitoring *Giardi*a and *Cryptosporidium* requires extensive and costly sample preparation and highly skilled technicians. These technologies may have limited sensitivity in: (1) detecting low pathogen concentrations or the loss of infectivity that signifies adequate treatment, and (2) distinguishing subtle differences between closely related species or strains, such as human pathogenic versus non-pathogenic *E. coli* (Rock and Gerba, 2014).

As a result, directly measuring pathogen concentrations in treated effluent is frequently not feasible. One approach is to estimate the log-removal performance of individual treatment barriers and calculate the log reduction value (LRV) for the entire treatment train as the sum of the individual barriers, which are separately calculated for viral, bacterial, and protozoal pathogens. Treatment performance is then evaluated in combination with microbial indicators and surrogates to determine if pathogen concentrations are reduced to levels that protect human health.

4.3.2 Continuous Monitoring of Microbial Indicator Organisms and Surrogates

Given the variety of pathogens that may be in wastewater and the impracticality of directly measuring each one, wastewater managers often assess treatment performance using indicator and surrogate monitoring frameworks. **Indicators** are *easily detectable microorganisms that represent a broader microbial group of interest, such as pathogens,* and **surrogates** are *bulk parameters capable of measuring treatment performance for specific group(s) of pathogens* (Brandhuber, 2016). Common indicators include:

- **Total coliform bacteria** indicate fecal contamination. Total coliforms occur naturally in the intestinal tract of people, other mammals, and in the environment. They are not usually considered harmful to people (EPA, 2017a). A subgroup is fecal coliform bacteria, the most common being *E. coli.* Because coliform bacteria are easy to culture in the lab and safe to work with, they are the primary indicator for fecal contamination. If large numbers of coliforms are detected, then other pathogens may be present, such as enteric viruses and parasitic protozoa

cysts and oocysts. Because outbreaks of *Giardia* and *Cryptosporidium* have occurred where drinking water met the total coliform standard (Ashbolt, 2001; Craun et al., 1997), public health officials and the water industry continue to seek other indicator organisms and validation processes to ensure the safety of treated water.

- ***Clostridium perfringens* spores** have been suggested as an alternative indicator for the inactivation and removal of viruses and parasitic protozoa (Payment and Franco, 1993). For recycled wastewater applications, *C. perfringens* is proposed as a surrogate/indicator for protozoa because the spores are of a similar size and resistance to disinfection and are commonly found in sewage (Ferguson et al., 1996; Rose et al., 2004). While studies evaluating microorganisms in disinfected recycled water have reliably detected total coliforms, *C. perfringens*, coliphages, enteric viruses, *Cryptosporidium* oocysts, and *Giardia* cysts, no strong correlations were documented for any indicator-pathogen combination in a 2005 research study (Harwood et al., 2005). The optimal indicator may be determined by local conditions and the treatment technologies used at individual WWTPs. For further discussion on the benefits and limitations of indicator organisms, refer to Osborn et al. (2004).

Table 4-3 summarizes pathogens of concern and the corresponding indicators that are commonly used to evaluate water quality or treatment performance.

Table 4-3. Pathogen Group of Concern and the Corresponding Water Quality Indicator

Pathogen Group of Concern	Water Quality Indicator for Treatment Barrier
Viruses	Commonly used indicators: Somatic coliphage, F+ RNA coliphage (e.g., MS2). Emerging indicators: Aichi virus and plant Pepper Mild Mottle Virus (PMMoV).
Parasitic Protozoa	Spores of *Bacillus subtilis* or *Clostridium perfringens* (sometimes total aerobic *Bacillus* spores).
Bacteria	*Escherichia coli,* enterococci, total and fecal coliform bacteria.

In many cases, indicator organisms may not be sufficiently sensitive to rapidly assess treatment process performance. To aid in this assessment, the surrogates listed in **Table 4-4** are used currently.

4.3.3 Indicators and Surrogates to Assess Human Health Risks in Agricultural Irrigation

Several recent studies have used indicators, surrogates, and direct pathogen measurement to assess the health risks of using tertiary treated recycled water to irrigate food crops.

A study by Rose et al. (1996) reported that recycled irrigation water that is treated through a series of biological treatment, sand filtration, and chlorination achieved log reductions for total/fecal coliform, *Cryptosporidium,* and *Giardia* spp. corresponding to a risk of infection of 10^{-6} to 10^{-8} following a single exposure to 100 mL of treated water. A report by Cooper et al. (2012) concluded that irrigating food crops with tertiary-treated water does not increase risks to public health as long as accepted water treatment and harvesting practices are followed. Other studies examined microbial activity on food

crops irrigated with water from contaminated surface sources or treated to standards less stringent than what is required by Title 22 (Draper et al., 2016; Guévremont et al., 2017; Stine et al., 2005).

It is worth noting that the FDA Produce Safety Rule (PSR) relied on *E. coli* as an indicator organism for the quality of agricultural water used for pre-harvest irrigation water (currently, this article is under four-year review). The PSR requires that irrigation water used for crops that are likely to be consumed raw should contain a Geometric Mean of not more than 126 and a Statistical Threshold Value of 410 generic *E. coli* CFU/100 mL, based on 20 samples collected over a two-year period (Havelaar et al., 2017). This requirement is less stringent than California's Title 22 regulation, which requires irrigation water applied directly on the edible portion of food crops to be treated to tertiary standards and maintain median total coliform MPN of ≤2.2 CFU/100 mL.

Table 4-4. Common Surrogates for Continuous Monitoring of Unit Process Performance

Process	Example Monitoring Parameters
Preliminary/primary treatment	Hydraulic residence time (HRT), reduction of total suspended solids (TSS), and total organic carbon (TOC)
Biological treatment (secondary)	Solids retention time (SRT), turbidity, TSS and TOC removal, dissolved oxygen
Membrane bioreactor	SRT, turbidity, HRT, dissolved oxygen
Activated carbon/ion exchange contactors	Removal of representative dissolved species through the contactor
Slow sand filter bag/cartridge	Turbidity, particle counts
Media filtration	Turbidity, particle counts
Microfiltration and ultrafiltration	Turbidity, membrane integrity tests including pressure decay tests, particle counts, bubble test
Reverse osmosis and nanofiltration	Removal of salts, total organic carbon (TOC), other dissolved species, or dyes (e.g., Trasar®)
Ozone	Ozone dose, including the product of dissolved ozone residual and contact time, reduction in ultraviolet light absorbance (UVA), temperature
UV disinfection and advanced oxidation	UV intensity, including UV transmissivity; and UV dose, which is the product of UV intensity and exposure time
Free or total chlorine	Disinfectant dose, which is the product of chlorine residual and contact time; ORP, and temperature

4.3.4 Pathogen Removal through Treatment of Disinfected Tertiary Recycled Water

The Panel addressed: (1) pathogen removal requirements for both drinking water and DTRW in California, (2) the reduction of pathogens through water recycling facilities that produce DTRW, and (3) the role of treatment design and operations in pathogen removal.

4.3.4.1 Pathogen Removal Requirements for Drinking Water and DTRW

The drinking water industry first verified the microbial safety of treated water by using a coliform standard: the absence of coliform in a 100-mL sample demonstrated that water was suitable for human consumption. Total coliform bacteria became the standard indicator for disinfection efficacy because they are more numerous than fecal coliforms and *E. coli* and are easier to measure (Ashbolt et al., 2001). With this framework, treated effluent was monitored to verify the microbial safety of the water.

The quantification of process performance developed in the late twentieth century, when the water industry realized that the coliform standard does not offer sufficient protection against more resistant pathogens, such as enteric viruses and protozoa. Regulations in the United States and abroad evolved to address three more pathogens: enteric viruses, *Giardia* cysts, and *Cryptosporidium* oocysts, based on removing enough organisms to meet an annual health-based target of less than one infection per 10,000 people. Because the pathogen concentrations considered protective of public health for viruses and parasitic protozoa are less than detection levels, treated effluent monitoring could not demonstrate adequate pathogen control (Macler and Regli, 1993; Regli et al., 1991; Trussell et al., 2013). Instead, regulations required a minimum degree of pathogen reduction through validated unit operations in a treatment train. Treatment trains that could demonstrate the required log reduction were considered to be protective of public health. Specifically, the Surface Water Treatment Rules requires a 4-$\log_{10}$ reduction of enteric virus, 3-$\log_{10}$ reduction of *Giardia*, and a minimum of 2-$\log_{10}$ reduction of *Cryptosporidium* (EPA, 1989; EPA, 1998; EPA, 2006).

Recycled water regulated under Title 22 has had a similar history. In addition to strict total coliform requirements, which include the median values below the detection limit (see **Chapter 2**), the requirements for DTRW also include a minimum virus reduction of at least 99.999 percent (5 $\log_{10}$) through the combined filtration and disinfection process. The default disinfection requirements—a chlorine disinfection CT of 450 (mg·min)/L with a 90-minute modal contact time—were demonstrated to provide 5 $\log_{10}$ reduction in combination with media filtration (Cooper et al., 2012). Other disinfection technologies are also allowed if they can demonstrate a 5-$\log_{10}$ reduction of F-specific bacteriophage MS2 or polio virus in the wastewater; a virus that is at least as resistant to disinfection as polio virus may be used for purposes of the demonstration (State Water Board, 2017).

As a result, it is possible to estimate the degree of bacterial and virus reduction in DTRW based on Title 22 treatment requirements. Assuming total coliform concentrations in untreated wastewater typically range from 10^8 to 10^{10} MPN per 100 mL, achieving the regulatory maximum of 2.2 MPN/100 mL would require a treatment train to achieve $\log_{10}$ reduction value (LRV) of 7.7 to 9.7 for bacteria (Tchobanoglous et al., 2004). Significant research has evaluated and compared indicators to bacteria, including under pilot-scale conditions with added surrogates to derive accepted performance criteria (Sharvelle et al., 2017; WHO, 2017a). Consequently, the degree of control against pathogenic bacteria can be estimated for a wide range of targeted bacterial pathogens.

Unlike enteric bacteria, virus control requires that a specified $\log_{10}$ reduction target be met, such as the 5-$\log_{10}$ reduction for human exposures. The requirement for virus control was developed from research that used poliovirus as the model virus (Cooper et al., 2012). Typically, most utilities seeking to use an alternative treatment process use the bacterial virus, MS2 coliphage, which is harmless to human health, as the model or surrogate virus. *Enterovirus* species could be used as a substitute, but they are more hazardous to handle. As with bacteria, not all viruses will demonstrate the same sensitivity to disinfection and removal processes. For example, 5-$\log_{10}$ MS2 inactivation by UV irradiation will not offer the same degree of protection against human adenoviruses, which have high resistance to UV inactivation (Beck et al., 2016). Nevertheless, considerable research has evaluated the relative sensitivity of various viral pathogens and indicators to different treatments. Again, extrapolations from these

indicators—total coliforms and MS2 phage—can offer estimates for the degree of removal or inactivation of a wide variety of human and animal pathogens (Hijnen and Medema, 2010).

4.3.4.2 Reduction of Pathogens through Water Recycling Facilities

Although pathogens of concern to human and animal health are effectively reduced through the use of water recycling treatment technologies, a best practice for any use of recycled water is to prevent concentrated wastes from entering the wastewater treatment facility in the first place. Therefore, the Panel recommends that facilities that produce DTRW for livestock watering develop a targeted source control program that complies with the National Pretreatment Program and includes technically based local limits to exclude waste from slaughterhouses/abattoirs and zoos, and other significant contributions of animal pathogens.

A benchmark study by Rose et al. (2004) quantified pathogen concentrations in raw wastewater and the removal of pathogens using water recycling facilities. The researchers monitored six different water recycling facilities for a number of pathogens and indicator organisms and conducted six separate sampling events at each facility. In **Figures 4-1a, 4-1b, and 4-1c**, the concentrations in untreated and secondary wastewater effluents are illustrated for the three regulated drinking water pathogens: enterovirus, *Giardia*, and *Cryptosporidium*.

4-1a. Enterovirus

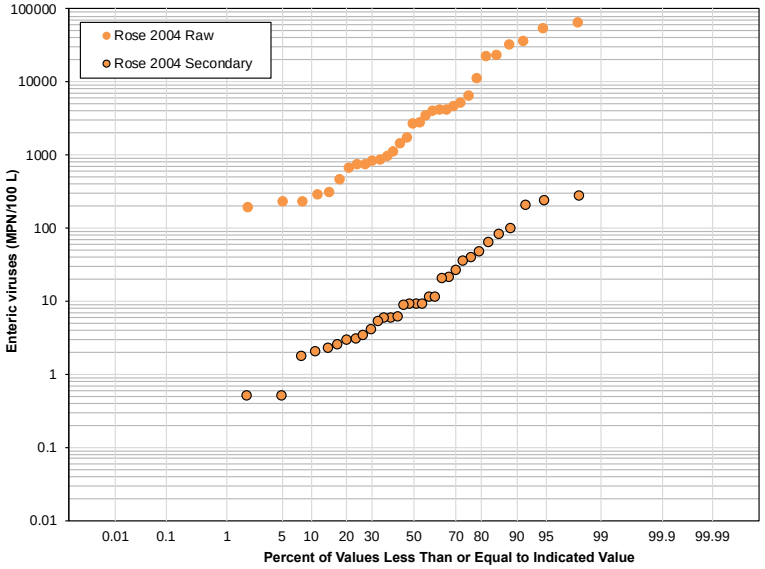

Figure continues, next page

4-1b. *Giardia* Cysts

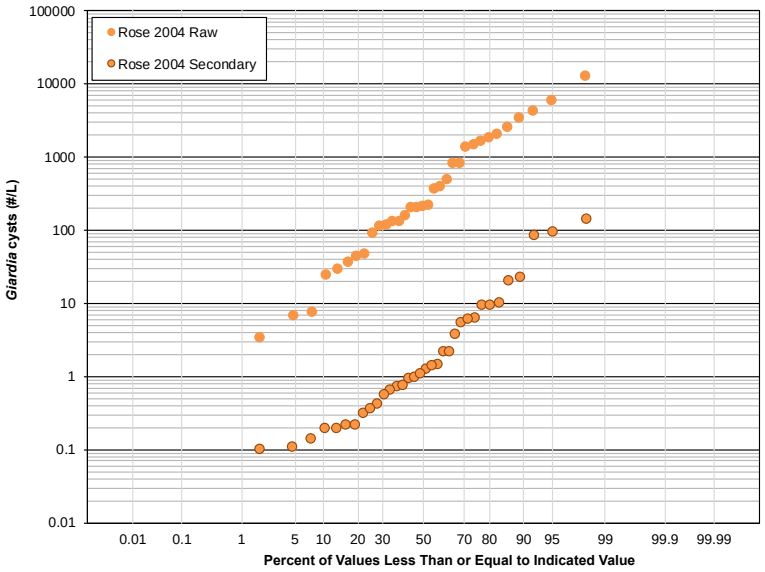

Figure continues, below

4-1c. *Cryptosporidium* Oocysts

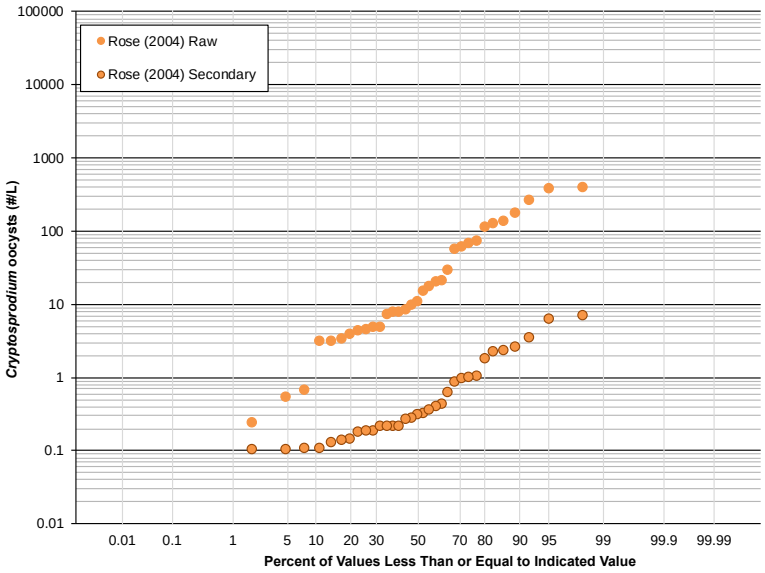

Figure 4-1a—c. *Raw wastewater and secondary effluent concentrations of (4-1a)* enterovirus*, (4-1b) Giardia cysts, and (4-1c) Cryptosporidium oocysts. Courtesy of Rose et al. (2004).*

An overview of the pathogen concentrations and typical removal performance through secondary treatment is presented in **Table 4-5**. Rose et al. (2004) also evaluated *Enterovirus*, *Giardia*, and *Cryptosporidium* LRVs for tertiary treatment, such as filtration and disinfection, as shown later in **Table 4-8**.

Table 4-5. Concentrations of Viruses and Parasitic Protozoa in Wastewater[a]

Pathogen	*90th Percentile Raw Wastewater Concentration (units/L)*	*Median Raw Wastewater Concentration (units/L)*	*Median Secondary Effluent Concentration (units/L)*	*Median Log_{10} Removal (LRV)*
Enterovirus	300 MPN/L	30 MPN/L	0.1 MPN/L	2.5
Giardia	4,000 cysts/L	200 cysts/L	1 cyst/L	2.3
Cryptosporidium	200 oocysts/L	10 oocysts/L	0.3 oocysts/L	1.5

[a] Source: Rose et al. (2004).

Additional data will become available in 2019 from a study that the State of California is funding to further characterize pathogen concentrations in raw wastewater (Olivieri et al., 2016; State Water Board, 2016). The Panel recommends that these additional datasets be incorporated into future evaluations of raw water concentrations and pathogen reduction values.

4.3.4.3 The Role of Treatment Design and Operations on Pathogen Removal

Biological Treatment. Per Title 22, feedwater to the tertiary filtration and disinfection processes must be an "oxidized wastewater…in which the organic matter has been stabilized, is non-putrescible, and contains dissolved oxygen." While multiple forms of biological treatment can achieve these requirements, the regulations do not require a specific technology to be used. Technologies range from simple trickling filters (first used in 1901) to complex activated sludge systems that provide biological nutrient control. The degree of organics destruction increases in these systems as a function of the age and complexity of the microbiological populations responsible for oxidation. The solids retention time (SRT), which is the average age of the microbiological populations in the system, correlates well with the degree of oxidation provided. Higher SRTs lead to greater overall reductions of dissolved organic carbon and chemical contaminants in the treated effluent (Gerrity et al., 2013). At this time, insufficient data are available to characterize how SRT affects pathogen reduction, but it is anticipated that higher degrees of biological treatment will provide greater pathogen reduction.

Filtration. The next barrier to pathogens is tertiary filtration. Title 22 allows for the use of both granular media filtration (GMF) and membrane filtration (MF), though it specifies different operational and effluent requirements for each (see **Table 2-2** in **Chapter 2**). While both technologies are acceptable to produce DTRW, the MF option removes more particles, including the size range of parasitic *Giardia* cysts, *Cryptosporidium* oocysts, and bacteria, and produces effluent of lower turbidity than GMF.

Disinfection. The final barrier for pathogen reduction is disinfection. By default, Title 22 requires chlorine disinfection achieving a minimum CT of 450 (mg·min)/L with a 90-minute modal contact time. Typically, chlorine disinfection of recycled water occurs via chloramine disinfection.

Alternative Disinfection Options and Pathogen Control. While the free and combined chlorine processes are credited for the same degree of virus disinfection, they vary in their ability to control other non-regulated pathogens. For example, the protozoa *Giardia* will experience a 3-Log_{10} inactivation if free chlorine is applied to achieve a minimum CT of 47 (mg·min)/L at 20˚C and pH = 6 (shown in **Table 4-6a**) but is not effectively inactivated by chloramine **(Table 4-6b)**.

Table 4-6a. CT Values* for 3-Log$_{10}$ Inactivation of *Giardia* Cysts with Free Chlorine

Chlorine Concentration (mg/L)	Temperature = 20˚C						
	pH						
	<=6.0	6.5	7.0	7.5	8.0	8.5	9.0
<= 0.4	36	44	52	62	74	89	105
0.6	38	45	54	64	77	92	109
0.8	39	46	55	66	79	95	113
1.0	39	47	56	67	81	98	117
1.2	40	48	57	69	83	100	120
1.4	41	49	58	70	85	103	123
1.6	42	50	59	72	87	105	126
1.8	43	51	61	74	89	108	129
2.0	44	52	62	75	91	110	132
2.2	44	53	63	77	93	113	135
2.4	45	54	65	78	95	115	138
2.6	46	55	66	80	97	117	141
2.8	47	56	67	81	99	119	143
3.0	47	57	68	83	101	122	146

*Adapted from EPA (2003). Units are min-mg/L.

Values in the table correspond to the CT value, which is the product of the chlorine concentration [C] and the contact time [T]. The units are milligrams per liter (mg/L) for C and minutes (min) for T, so the product results in units of (mg·min)/L.

Table 4-6b. CT Values* for 3-Log$_{10}$ Inactivation of *Giardia* Cysts with Chloramine at pH 6-9

Temperature (˚C)					
< = 1	5	10	15	20	25
3,800	2,200	1,850	1,500	1,100	750

* Adapted from EPA (2003). Units are min-mg/L.

Values in the table correspond to the CT value, which is the product of the chlorine concentration [C] and the contact time [T]. The units are milligrams per liter (mg/L) for C and minutes (min) for T, so the product results in units of (mg·min)/L.

UV disinfection delivered in compliance with recycled water regulations provides a significant barrier to many pathogens, including those shown in **Table 4-7**. A UV system designed for recycled water must provide doses of 80 and 100 mJ/cm^2 to treat GMF and MF effluents, respectively (NWRI, 2012). While UV provides an equivalent degree of protection against viruses as the 450 (mg·min)/L chloramine CT, it also protects against protozoa. For example, a UV dose of 22 mJ/cm^2 will meet the EPA's drinking water requirements for 4-log$_{10}$ inactivation of both *Giardia* and *Cryptosporidium.*

Table 4-7. Ultraviolet Dose Requirements in mJ/cm^2 for 0.5- to 4-Log$_{10}$ Inactivation *Cryptosporidium*, *Giardia*, and Enteric Viruses[a]

Target Pathogen	Log$_{10}$ Inactivation							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Cryptosporidium	1.6	2.5	3.9	5.8	8.5	12	15	22
Giardia	1.5	2.1	3.0	5.2	7.7	11	15	22
Enteric viruses	39	58	79	100	121	143	163	186

[a] Code of Federal Regulations. Refer to 40 CFR 141.720(d)(1).

In summary, the Title 22 regulations require a minimum level of physical and biological treatment followed by filtration and disinfection for the control of microorganisms (total coliforms and enteroviruses). Because several technologies can be used for secondary wastewater treatment, tertiary filtration, and disinfection, a range of pathogen reduction is expected. An estimate of pathogen reduction through various treatment trains is presented in **Table 4-8**.

Table 4-8. Estimated log reduction values for Title 22-compliant treatment trains for DTRW

Pathogen/ Indicator	Treatment						Log_{10} Removal
	Primary/ Secondary	*Filtration*		*Disinfection*			
		GMF	MF	Chloramine	Chlorine	UV	
Virus	2.5	1		5[a]			8.5
			2	5[a]			9.5
Giardia	2.3	1		0			3.3
					2		5.3
						6	9.3
			4	0			6.3
					2		8.3
						6	12.3
Cryptosporidium	1.5	1		0			2.5
					0		2.5
						6	8.5
			4	0			5.5
					0		5.5
						6	11.5
Bacteria	Treatment must reduce total coliform bacteria to <2.2 MPN/100 mL[a]						8.7

Acronyms: GMF = Granular Media Filtration. MF = Microfiltration. UV = Ultraviolet disinfection. MPN = Most probable number. mL = Milliliter.

[a] Title 22 regulations require 5-log_{10} virus inactivation and 7-day running median total coliform reduction to <2.2 MPN/100 mL.

4.3.5 Occurrence of Pathogenic Microorganisms in DTRW

The concentrations of enteric virus, *Giardia, Cryptosporidium*, and coliform bacteria remaining in DTRW can be estimated based on: (1) the concentration of pathogens entering the water recycling facility in the untreated wastewater, and (2) the degree of removal or inactivation of those pathogens by treatment. Variations in the unit processes may cause significant differences in the reduction of these three pathogen groups.

As a conservative measure, the Panel evaluated which Title 22-compliant treatment trains could effectively reduce the concentration of regulated pathogens to drinking water standards. The Panel concluded that matching the drinking water criteria for pathogen control would be an appropriate and conservative goal for DTRW used for livestock watering because:

- Systems meeting this level of protection would be equivalent to potable municipal supplies for control of enterovirus, *Giardia,* and *Cryptosporidium*. Because municipal supplies are used for livestock watering, the use of an alternative supply, including DTRW, should not increase the animal's risk of disease from these pathogens. The quality of DTRW will be higher than other, existing sources of water for livestock, including untreated surface water.
- Wastewater that feeds water recycling facilities originates primarily from households and commercial properties, so the concentration of human-specific pathogens should be significantly higher than animal-specific pathogens. For example, the concentration of *Cryptosporidium hominis* (human-infecting species) should exceed the concentration of *C. bovis* (cattle-specific species). Therefore, the reduction of *C. hominis* below the human health risk-based thresholds should provide a conservative degree of protection against *C. bovis.*

Table 4-9 summarizes the DTRW treatment trains capable of reducing viruses, *Giardia,* and *Cryptosporidium* concentrations to the less than 1 in 10,000 risk level used to define the microbial safety of drinking water. All of these trains achieve the acceptable drinking water concentrations when treating typical raw wastewater (i.e., those containing median pathogen values). They also maintain drinking water values within a factor of 5 under more extreme pathogen concentrations (i.e., 90th percentile). One common process in these treatment trains is UV disinfection, which provides robust protection against a range of pathogens.

Table 4-9. Estimated Pathogen Log Removal, Influent and Effluent Concentrations, and Targets for Disinfected Tertiary Recycled Water Using Filtration and Disinfection

Pathogen/ Indicator	Treatment						Influent Concentration[a]		Effluent Concentration		Drinking Water Target[b]
	Filtration		Disinfection			Log Removal					
	GMF	MF	CC	FC	UV	Total	Median	90th	Median	90th	
Virus	X		X	X	X	8.5	30	300	9.5E-08	9.5E-07	2.20E-07
		X	X	X	X	9.5			9.5E-09	9.5E-08	2.20E-07
Giardia	X				X	9.3	20	4000	1.0E-08	2.0E-06	6.80E-06
		X		X		8.3			1.0E-07	2.0E-05	6.80E-06
		X			X	12.3			1.0E-11	2.0E-09	6.80E-06
Crypto	X				X	8.5	10	200	3.2E-08	6.3E-07	1.70E-06
		X			X	11.5			3.2E-11	6.3E-10	1.70E-06
Bacteria						8.7	1.00E+08	1.00E+09	2.2	2.2	2.2

Abbreviations: *Crypto* = *Cryptosporidium*. GMF = granular media filtration. MF = microfiltration. CC = combined chlorine. FC = free chlorine. UV = ultraviolet disinfection.

[a] Based on Rose et al. (2004).

[b] Based on annual health target of 10^{-4} infections per person, which is used in the EPA drinking water and California potable reuse regulations.

The Panel's recommendations are based on concentrations of pathogens typically observed in municipal wastewater discharged by domestic, industrial (including hospital), and commercial sources.

Wastewater produced at livestock slaughtering and processing facilities contains high loads of animal pathogens, and therefore would require advanced treatment beyond Title 22 requirements to ensure the water is microbially safe for use as a livestock watering source.

Existing reports on concentrations and reductions in human pathogens were used to estimate concentrations of infectious animal pathogens in DTRWs. The pathogens of primary concern to human and animal welfare are presented in the appendices along with estimated concentrations in untreated wastewater and reductions through treatment. Assumptions were made about:

1. Concentrations of animal pathogens in untreated domestic wastewater.
2. The degree of removal and disinfection through the recommended treatment train of secondary treatment, GMF, and UV disinfection.
3. Corrections to account for differences between human and animal pathogen concentrations.

4.4 Potential Microbial Risks of Using DTRW as a Non-Dairy Livestock Water Supply

In a human-health context, the microbial acceptability of drinking water is determined by comparing the concentration of human pathogens in the finished water to a target concentration. In many cases, such as for enteric viruses, *Giardia*, and *Cryptosporidium*, this target concentration is determined through a quantitative microbial risk assessment (QMRA) that links the pathogen's infectivity, the consumption of drinking water, and the probability of infection. This approach is not practical for pathogens that affect livestock because of the lack of information related to: (1) concentrations of animal pathogens in domestic wastewater, (2) concentrations of animal pathogens in the treated water, and (3) dose-response information linking pathogen exposure to probability of infection for the myriad pathogen-animal host pairs. As an alternative solution, the Panel compared concentrations of animal pathogens to the acceptable human health risk-based values. **Appendix 4-D** describes this comparison.

4.5 Livestock Regulatory Perspectives on Pathogenic Microorganisms in DTRW

DTRW has the potential to improve animal health in cases where existing water quality is poor. For example, surface water used for agricultural irrigation and processing may act as a reservoir for pathogens and has emerged as a primary source of pre-harvest produce contamination. However, studies on the acceptability of DTRW for food crop production, including crops in which edible portions are in direct contact with DTRW, have concluded that DTRW treatment reduces the concentrations of pathogens to levels that do not measurably increase public health risk (Cooper et al., 2012).

The use of microbiologically contaminated surface water can contaminate produce directly and indirectly through introduction into the soil. Because surface water sources such as ditches, canals, ponds, rivers, lakes, and streams are influenced by the surrounding environment, many water sources that are currently used to irrigate agricultural lands or for animal watering are of lower quality than DTRW. Common surface water pollution can include runoff, animal intrusion, illegal dumping, or other contaminant discharge. In fact, irrigation with untreated surface water has been repeatedly associated with the isolation of key pathogens such as *L. monocytogenes, Salmonella*, or Shiga toxin-producing *E. coli* (STEC) from the pre-harvest environment. Microbial loads have been evaluated in surface waters

across agricultural regions to protect public health (Bartz et al., 2017; Strawn et al., 2014; Erickson et al., 2010; Guan et al., 2001; Harwood et al., 2005; Hipsey et al., 2008; Holvoet et al., 2014; Ibenyassine et al., 2006; Ijabadeniyl and Olugbara, 2013; and Kayed, 2004).

4.5.1 Industry Concerns with Waterborne Outbreaks

Livestock producers dedicate their lives to producing high-quality, safe, and nutritious food products. Many farmers and ranchers have implemented progressive practices for animal husbandry and business management, water and environmental sustainability, and state-of-the-art animal welfare and preventative health programs. In addition, veterinarians serve "the indispensable role as stewards of animal health, animal welfare, and public health."[29] This community of practitioners understands that pathogens of concern in water supplies can affect animal health, quality of animal food products, and human health. Veterinary scientists contributing to this report caution that the risk of pathogenic infection in livestock could be amplified by the cumulative effects of long-term exposure to DTRW, and that data gaps exist for pathogens in wastewater and DTRW. Without this data, it is difficult to accurately estimate the increased probability of infection if DTRW is approved for livestock watering Therefore, it is important to the livestock industry and veterinary scientists to characterize the risks using a scientific approach.

It is important to note that for certain pathogen outbreaks, the emergency disease control response from the California Department of Food and Agriculture (CDFA) and the USDA includes culling (slaughter) of individual stock animals and, in some cases, the culling of entire herds. While culling is a necessary aspect of animal husbandry to prevent disease, it causes dramatic and unplanned economic losses on both the local and regional scales and may undermine international consumer confidence in California's agricultural products. Because California's agricultural diversity is essential to the state's economy and international food security, any new animal husbandry practice that creates a potential risk to diminish California's standing in the global food production market warrants cautious and disciplined examination.

29 California Department of Food and Agriculture Animal Health and Food Safety Services https://www.cdfa.ca.gov/ahfss/

4.5.2 Additional Pathogenic Microorganism Reduction

The Panel evaluated human and animal pathogens in DTRW and concluded that using it for livestock watering will not significantly increase the risk of infections above existing drinking water sources if the BMPs recommended by the Panel are implemented:

1. Targeted source control to eliminate inputs of slaughterhouse/abattoir and zoo wastes to WWTPs that produce DTRW for livestock water use.
2. Enhanced treatment requirements to include UV disinfection.
3. Maintenance of disinfectant residuals in the DTRW distribution system.
4. Animal health and product monitoring.

The Panel also emphasizes that the drinking water exposure route is very low compared to the dust, soil, and excreta exposure in animal feeding operations.

Figure 4-2 illustrates the recommended BMPs:

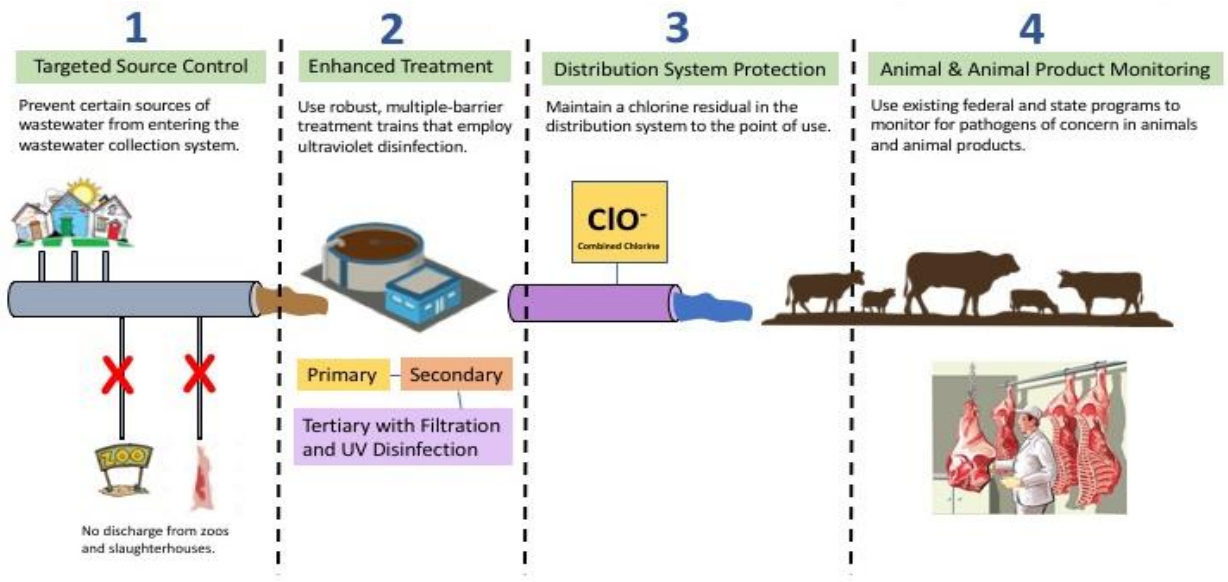

Figure 4-2. *Recommended BMPS for producing recycled water for non-dairy livestock.*

These BMPs should reduce pathogen concentrations to levels at or below human drinking water thresholds, which the Panel believes to be a highly conservative endpoint. This degree of treatment should provide protection under both average and extreme (90th percentile) concentrations of pathogens in the raw wastewater. **Table 4-10** outlines BMPs for pathogens of concern.

Table 4-10. Controlling Pathogens of Concern through BMPs for Title 22-Compliant DTRW

Pathogen	Targeted Source Control[a]	Enhanced Treatment[b]	Distribution System Protection[c]	Animal and Animal Product Monitoring[d]
Bacteria				
Salmonella enterica	✓	✓	✓	✓
Mycobacterium tuberculosis complex				✓
Mycobacterium avium complex/ *Mycobacterium avium paratuberculosis*			✓	✓
Clostridium perfringens		✓		
Campylobacter jejuni/coli	✓	✓	✓	
Fungi				
Microsporidia		✓		
Helminths				
Taenia solium and Taenia saginata	✓	✓		✓
Prions				
Bovine Spongiform Encephalopathy	✓			✓
Protozoa				
Cryptosporidium parvum	✓	✓		
Giardia lamblia complex	✓	✓		
Neospora caninum	✓	✓		
Toxoplasma gondii	✓	✓		
Viruses				
Hepatitis E	✓	✓	✓	
Influenza Viruses	✓	✓	✓	✓

a Targeted source control involves preventing discharge from slaughterhouses or zoos from entering the wastewater collection system.

b Enhanced treatment includes primary treatment, secondary treatment, and tertiary treatment with filtration and ultraviolet disinfection.

c Distribution system protection involves maintaining a chlorine residual in the distribution system to the point of use.

d Animal and animal product monitoring involves the use of existing state and federal programs to monitor for pathogens of concern in animals and animal products. This column refers specifically to the California Department of Food and Agriculture's "2018 List of Reportable Conditions for Animals and Animal Products" at https://www.cdfa.ca.gov/ahfss/Animal_Health/pdfs/CA_reportable_disease_list_poster.pdf. In that list, the reporter includes "Any licensed veterinarian, any person operating a diagnostic laboratory, or any person who has been informed, recognizes, or should recognize by virtue of education, experience, or occupation, that any animal or animal product is or may be affected by, or has been exposed to, or may be transmitting or carrying any of the following conditions, must report that information."

While the risk from this—or any other potable—application cannot be reduced to zero, it meets or exceeds the thresholds typically used for safe drinking water. Using this benchmark to designate significant risk, the Panel concludes that DTRW that is treated according to these BMPs will not pose a significant threat to animal health compared to potable municipal supplies.

4.6 Conclusions and Recommendations

The Panel agreed that there is sufficient evidence that not all forms of DTRW are safe for non-dairy livestock watering. Therefore, the Panel recommends that DTRW delivered for livestock watering should be produced in accordance with BMPs that go beyond what is currently required by Title 22.

Although the Title 22 requirements for DTRW contain uniform criteria for the reduction of certain microorganisms (enteric virus and total coliform), they do not explicitly address other pathogens that may be of concern in livestock watering. Therefore, to provide more consistent protection against this wider spectrum of pathogens, the Panel recommends the State Board adopt the following BMPs to ensure the safety of people and animals:

- Require any DTRW system that provides drinking water to livestock to develop and maintain a targeted source control program that complies with the National Pretreatment Program and includes technically based local limits to exclude waste from slaughterhouses/abattoirs, zoos, and other significant sources of animal waste.
- Require any DTRW system that provides drinking water to livestock to achieve disinfection using an approved ultraviolet (UV) system that meets the disinfection criteria in Title 22 for DTRW. The disinfection must, when combined with the filtration process, be demonstrated to inactivate and/or remove 99.999 percent of the plaque forming units of F-specific bacteriophage MS2, or polio virus in the wastewater. The Panel agreed that UV disinfection is a more effective disinfectant than chlorine for many pathogens of concern.
- Require any DTRW system that provides drinking water to livestock to maintain an appropriate disinfection residual in the DTRW distribution system to prevent microbial growth. The Panel recommends 0.2 mg/L free chlorine or 0.5 mg/L chloramine at the point of use to prevent regrowth of opportunistic pathogens.

The Panel also encourages the State Water Board to coordinate with relevant Federal and State agencies (e.g., USDA, FDA, or CDFA) to track the health of animals in herds that receive DTRW through a periodic review and analysis of animal health monitoring data.

In addition, the Panel recommends that the State Water Board consider conducting additional analysis on new data that will soon be available on pathogen concentrations in raw wastewater and the pathogen reductions. The Panel recommends that these additional datasets be incorporated into future risk evaluations.

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CHAPTER 5: POTENTIAL RISKS TO PEOPLE AND NON-DAIRY LIVESTOCK—CHEMICALS

- Waterborne chemicals of concern and their effects on people and livestock animals.
- Chemical residues in animal products are the most likely pathway for human toxicity.
- Lack of dose-response data for livestock animals requires certain assumptions in the analysis and leads to application of human health standards to animals.
- Worst-case scenario analysis indicates that chemical residue accumulation in meat and egg products from animals exposed to DTRW would not approach established regulatory tolerance levels.

5.1 Introduction

Section 8 (b) of the Federal Toxic Substances Control Act (TSCA) requires the EPA to compile, maintain, and publish a list of chemical substances that are manufactured or processed in the United States. Today, EPA lists about 85,000 chemicals on this inventory.

Chemicals and chemical compounds are ubiquitous in California today. This chapter describes chemicals of concern that are relevant to DTRW and that could negatively affect the health of non-dairy livestock and people who eat meat and eggs. The Panel focused on potential health risks of waterborne chemical contaminants that could lead to negative long-term public health consequences for people and animals.

5.2 Chemicals of Concern

When considering whether trace-level chemicals in DTRW would be safe for livestock and human consumers, a primary concern of the Panel was the lack of data on direct toxicity and residues. While the Panel believes the overall risks to livestock and people from chemicals are low, several variables could not be evaluated with certainty given the limited data on animal health and chemicals.

For example, there is a lack of data on: (1) toxicity of many chemicals in livestock; (2) absorption, distribution, metabolism, and elimination (ADME) in livestock; and (3) animal tissue residues for numerous chemicals at various exposures and durations. Nevertheless, chemical contaminants in DTRW are present in trace amounts at the level of parts per billion to parts per trillion; therefore, only the most hazardous chemicals would be of potential toxicological concern for livestock watered with DTRW. Because species-specific toxicity data were not available for most chemicals, all livestock species were considered to be equally sensitive to any given chemical of concern.

In the absence of livestock toxicity information, human benchmarks often are applied to livestock; such an approach is highly conservative because benchmarks developed for human risk assessments typically incorporate safety factors that reduce acceptable exposures two or more orders of magnitude lower than the lowest dose known to cause adverse effects in test animals. While carcinogenicity, genotoxicity, and allergenicity are major concerns for human health, they are less concerning for livestock health due to the short lifespan of most food production animals. If broader datasets for tissue residues had been available for personal care products, industrial chemicals and solvents, human pharmaceuticals, and water disinfection byproducts, then the Panel could have assessed human safety concerns related to chemical residues more accurately. In the absence of data on tissue residues, the Panel used the worst-case scenario to estimate the concentrations of compounds in animal food products and the subsequent human exposures through the consumption of meat. **Figure 5-1** illustrates potential pathways for human chemical exposure through meat and eggs. Example calculations for several classes of chemicals are shown in **Appendix 5A.**

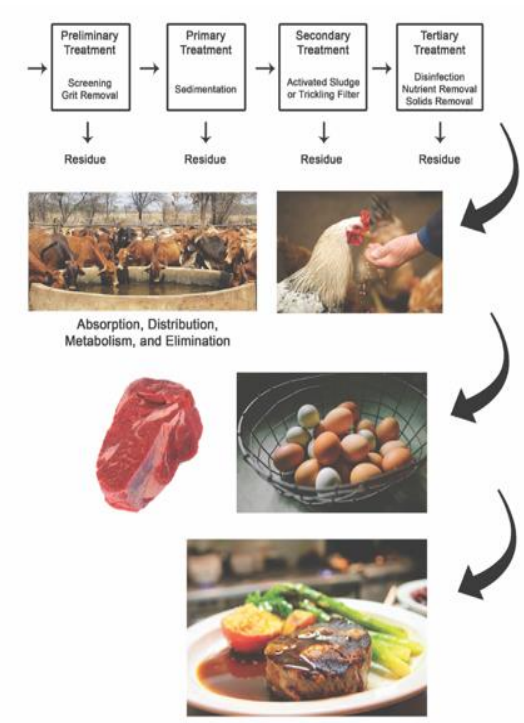

Figure 5-1. *Pathway for the chemical exposure of people consuming livestock-derived foods.*

The Panel did not consider: (1) exposures of livestock to metabolites or degradation products, (2) exposures to chemical mixtures, except in rare instances in which such exposures might have been incorporated into the design of a referenced toxicological study, (3) exposures of livestock to other sources of chemicals (such as medicated or contaminated feed) through pathways other than water or the environment, such as soil and bedding material, or (4) exposures of livestock to chemical contaminants introduced past the point of the DTRW supply. The Panel noted that toxicity assessments of individual compounds account for the endogenous generation of metabolites during the ADME process.

5.2.1 Chemicals of Concern: Animal Health

Available empirical evidence suggests that DTRW is safe for livestock use. It is known that DTRW has been used for more than 25 years without known incidence in Sonoma County, California, where the City of Santa Rosa provided DTRW to approximately 70 ranchers who are linked to the water distribution system (Moore, 2014). However, there was no active monitoring program to report data on this practice. In addition, DTRW has a long history of successful use for food crop irrigation, including root crops and salad crops that contact DTRW directly on edible portions of the plants. A lower quality of recycled water is allowed to irrigate pastures for dairy animals and fodder crops (Christian-Smith et al., 2010).

To assess threats to livestock health from chemical exposures in which no species-specific toxicity information is available (e.g., LD_{50}, LOAELs, NOAELs, ADI), the Panel referred to benchmarks used to protect human health. This approach is very conservative; for example, while human benchmarks consider potential carcinogenic, allergenic, and immunogenic endpoints, these toxicities are rarely considered for livestock species because of the generally short lifespans of these animals.

Numerous texts describe exposures to, and adverse health effects of, manmade and naturally occurring chemicals in animals (Cheeke, 1998; Gupta, 2012; Plumlee, 2004). For livestock species, most available toxicological data relate to well-recognized categories of chemicals that livestock are exposed to, including: drugs used to treat disease, promote growth, or increase productivity; pesticides (especially insecticides); natural toxins (e.g., plant toxins, mycotoxins, blue-green algae toxins); other common toxicants, such as lead and other metals; and petroleum hydrocarbons.

Other data about chemicals of concern for livestock, similar to the EPA CCLs, do not exist, and there is limited information available on acceptable concentrations of chemicals in water intended for livestock watering. In addition, for many chemicals included on the CCLs, little toxicity data was available for food animals. Typically, concerns about chemical exposures in livestock focus on acute to subacute effects. For many chemicals, chronic exposure is not a primary concern unless the chemical is likely to bioaccumulate in animal products destined for human consumption.

Further, the Panel found only one controlled toxicological study investigating the use of recycled water in animals. Gruener (1978) investigated effects of providing RO-treated water to mice in a series of studies lasting up to 150 days. The researcher concentrated a volume of 400,000 L of RO-recycled water to 200 L (with a TOC content of 700 mg/L) and incorporated the concentrate into a gel-type diet for mice. More than 900 mice were studied, and several endpoints, including growth, reproduction, mutagenesis, blood chemistry, tissue pathology, and mortality were used to evaluate animal health. Across all live-phase studies, the author reported only marginal changes that could not be associated with any pathological syndrome.

While the study provided no evidence of overt toxic effects, and little evidence of more subtle effects in live animals, the *in vitro* tests were positive for "general toxicity, mutagenicity, and carcinogenicity." The author did not report the effects of un-concentrated recycled water on *in vitro* test results. Because the TOC content of the test water was 100 to 1,000 times the TOC content expected for DTRW, and organic constituents present in the water were not chemically defined, the study only generally informed the Panel on the safety of DTRW produced in California. That is, DTRW produced in California is of much higher quality that that used by Gruener (1978), and any toxic effects would be difficult to discern without the use of more test animals and more sensitive endpoints.

Differences in species can sometimes be significant when discussing the sensitivity to high concentrations of acutely toxic chemicals. For example, nitrates are much more toxic to ruminants, such as cattle, goats, and sheep, than they are for monogastric animals, such as swine, because nitrate is reduced in the rumen to the much more toxic nitrite form. For the purposes of this report, species sensitivity differences were not addressed.

5.2.2 Chemicals of Concern: Human Health

The Panel recognized that chemicals of human health concern that could be present in DTRW may not be of concern to veterinarians with respect to animal health; however, if those same chemicals were present as residues in meat and eggs because the livestock drinking water source was DTRW, then they would be relevant to the Panel's charge. Chemicals of public health concern in tertiary waters have been reviewed by many sources (Anderson et al., 2010; Guo et al., 2010; Focazio et al., 2008; MWH, 2007).

Because traces of many different chemicals could potentially contaminate drinking water sources, the Safe Drinking Water Act (SDWA) authorized the EPA to develop a Contaminant Candidate List (CCL), which is a compilation of prioritized chemicals and waterborne pathogens for regulators. The most recent lists—the CCL 3 (2009) and CCL 4 (2016)—were established by identifying a "universe" of natural and synthetic contaminants, including chemicals and potential waterborne pathogens, screening the chemicals and pathogens for risk based on the potential for occurrence in water and effect on human health, and selecting priority contaminants.

Chemicals of concern can be natural or synthetic, but generally they are classified in the following categories: human and animal pharmaceuticals, inorganic elements, personal care products, water disinfection byproducts, agrochemicals (such as pesticides, herbicides, and fungicides), industrial chemicals, and banned long-lasting organics now considered environmental pollutants (such as DDT and PCPs). The EPA uses the CCL to identify contaminants of high concern for future regulation and, when appropriate, to codify in National Primary Drinking Water Regulations (NPDWR).

The NPDWR establishes maximum contaminant levels (MCLs), which are legally enforceable limits, on specific, high-risk contaminants for human drinking water. MCLs are based on extensive toxicological evaluations of each chemical, known human health risks, and potential occurrences in water at levels of concern. Municipal water treatment plants are required to monitor drinking water for contaminants that are identified under NPDWR (EPA, 2017a). Failure to meet these standards may prompt enforcement actions against municipalities. A list of chemicals and their associated MCLs, per the NPDWR, is provided in **Appendix 5B.**

Chemical contaminants included in the primary drinking water standards are only a small subset of chemicals identified in the CCL. **Appendix 5C** lists chemicals of potential human concern from CCL 3 and CCL 4.

MCLs codified in the NPDWR are binding upon states; however, individual states (including California) may enforce water quality standards more stringent than those promulgated by the EPA. That is, a state may establish standards for chemicals not included on the NPDWR or may enforce MCL standards more stringent than those established by the EPA. To this end, the State Water Board has instituted Drinking Water Notification Levels (State Water Board, 2018) for chemicals of concern in California. Most of these

chemicals are included in the CCL 4, but not all, for example, boron.[30] See **Appendix 5D** for drinking water notification levels in California.

5.2.3 Disinfection Byproducts

The Panel was interested in disinfection byproducts (DBPs) that could be introduced into tertiary water during the disinfection process. DBPs are a class of more than 600 chemicals that may form during water treatment processes that use chlorine, ozone, chloramine, and(or) chlorine dioxide (Richardson et al., 2007). California-produced DTRW, which is approved for irrigation of crops and is now being evaluated for use as a livestock water source, does not undergo advanced treatment, such as reverse osmosis, to remove DBPs after disinfection.

Using DTRW for livestock watering would expose animals to DBPs. Specific DBPs including bromate, chlorite, trihalomethanes (the sum of tribromomethane [bromoform], trichloromethane [chloroform], and bromodichloromethane), and N-nitrosodimethylamine (NDMA) are regulated in potable water and toxicological data is available for them. Other DBPs, although identified, are not yet regulated and extensive toxicological testing has not been performed on purified compounds (Richardson et al., 2007).

Because most DBPs are typically present in drinking waters at low μg/L (ppb) concentrations (or less) (Richardson et al., 2007), acute toxic effects are not considered a likely consequence of ingesting DBPs in treated water. Chlorate, which may occur in water at relatively high concentrations (high μg/L), is a common degradation product in water treatment systems that use hypochlorite disinfection processes (Stanford et al., 2011; Breytus et al., 2017). Chlorate, however, is well tolerated by livestock (Smith et al., 2012) even at relatively high doses, and was not overtly toxic to rats consuming up to 2000 mg/L in drinking water (NTP, 2005).

For most DBPs, risk assessors are primarily concerned with chronic toxicological endpoints such as cancer, tumorigenesis, and reproductive or developmental anomalies. A major problem in assessing DBPs is that they occur as complex mixtures of bewildering numbers of compounds and are present at low concentrations. As such, toxicological profiles of individual chemicals may not adequately predict the toxicological profiles of the same compounds in disinfected waters.

To address questions on the collective toxicity of DBPs in disinfected water sources, several lifetime rodent studies have been conducted using various water sources and methods of concentrating low-level contaminants. For example, Kool et al. (1985) dosed rats for 106 weeks with DBPs extracted from drinking water at exposure levels of 40 (males) to 68 (females) times those expected for human consumers of water.

Although extracts were mutagenic in the Ames test (which is used to determine the mutagenic activity of chemicals by observing whether they cause mutations in sample bacteria) consistent with findings by Gruener (1978), no treatment-related effects on animal weights, mortality, tissue histopathology, or tumor incidence were measured. A decade later, Condie et al. (1994) reported results from a two-year

[30] The California State Water Board maintains a current list comparing maximum contaminant levels and public health goals (PHGs) for regulated contaminants in drinking water online at https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/MCLsandPHGs.html

rat study using a reverse-osmosis concentrate of drinking water, a reverse-osmosis concentrate of reclaimed water, and an ultra-filtered concentrate of reclaimed water from Denver, Colorado. No carcinogenic effects were detected for water containing up to 500-fold chemical concentrates.

More recently, Narotsky et al. (2013) conducted a comprehensive, multi-generational study on the toxicity of DBPs prepared from chlorinated, reverse osmosis concentrates of surface waters. Water concentrates (136-fold) containing high levels of DBPs (chloroform, 7109 μg/L; bromodichloromethane, 3279 μg/L; bromoform, 59 μg/L; dichloroacetic acid, 4524 μg/L; trichloroacetic acid, 6748 μg/L; NDMA, 0.091 μg/L; chlorate, 27.6 mg/L) were provided continuously to pregnant rats and their F1 progeny, which were bred to produce an F2 generation (Pressman et al., 2010). No effects were detected on pup weight, prenatal loss, pregnancy rate, gestation length, puberty onset in males, growth, estrous cycles, hormone levels, immunological endpoints, and most neurobehavioral endpoints, and no evidence of maternal toxicity was presented by dams. Slight effects of delayed puberty for F1 females, reduced caput epididymal sperm counts in F1 adult males, and increased incidences of thyroid follicular cell hypertrophy in adult females were of unknown toxicological significance (Narotsky et al., 2013).

The collective implications of these studies for livestock production are straightforward. First, because concentrations of DBPs in DTRW are below the high concentrations present in the water used by these studies, we would not expect acute toxicological effects in livestock. Second, carcinogenic effects would not be expected in livestock because none were observed in chronic studies with rodents, and food animal species would not typically be exposed to DTRW for their entire lifetime because they are harvested at the end of the growing period. For breeding stock that have a longer lifespan, adverse reproductive and/or developmental effects also would not be expected because none have been documented in long-term trials with experimental animals.

5.3 Approach for Assessing Chemicals

To address chemicals, the Panel considered both: (1) animal health and safety, and (2) the magnitude and safety of chemical residues in animal products that people eat.

5.3.1 Chemical Residues in Animal Products: Human Health and Safety

The Panel agreed that direct risks to non-dairy livestock from chemicals within DTRW are extremely low, and that risks to people eating meat or other products from those animals would be even lower. However, the Panel acknowledged that consumers do not always interpret risk the same way that the scientific community does (Verbeke et al., 2007). Indeed, Tucker et al. (2006) documented that 33 percent of consumers in the United States ranked chemical residues as a serious risk (the highest risk category offered), and 31 percent ranked bacterial contamination as a serious risk. This demonstrates a public misperception, because illnesses from foodborne pathogens exceed those from chemical residues, including allergens, by an order of magnitude (Borchers et al., 2010). A detailed discussion about the human health effects of chemical residue and clearance is in **Appendix 5-F**.

5.3.2 Chemical Residues: Meat Produced in the United States

As described in **Chapter 3**, the USDA FSIS is charged with ensuring that residues of approved animal drugs, illicit drugs, and environmental contaminants (mostly pesticides) in the meat supply in the United States do not exceed regulatory thresholds. Strategies for scheduled, targeted sampling at slaughterhouses are described annually in the FSIS *Blue Book* (FSIS, 2017), including the statistical basis for the sampling plan, which is designed to detect a 1-percent violation rate with 99.97-percent probability, a 0.5-percent violation rate with 98-percent probability, and a 0.3-percent violation rate with 90-percent probability. Although residue data are made public by the FSIS, there is usually a brief delay before the publication of violative and non-violative residue summaries, which are available in the FSIS *Red Book*. In addition, the numbers of samples and violations within animal species, production class, and violative residue are summarized and published.

The Panel requested preliminary, unconfirmed residue data that the FSIS compiled from thousands of meat samples collected between October 2015 and April 2017. These meat samples were screened for animal health drugs (~17,000 analyses for each drug), pesticides (~4,350 samples for each analyte), and trace metals (~2,200 samples for each metal). The FSIS business process requires confirmation or quantification only for those compounds that exceed the minimum level of applicability (MLA) of the multiresidue screening assay and also meet other confirmatory criteria. Specifically, the data used by the Panel consisted of screening results only, not the quantitative results of confirmatory assays run after positive screens; therefore, the data used by the Panel represent a worst-case exposure scenario. The true number of confirmed violations for the dataset was only a fraction of those identified for additional scrutiny by the multi-residue screening methods. Acknowledging the implicit bias in using preliminary screening data, the Panel used the FSIS data to establish baseline levels of chemical residues in commercially raised meat animals across the United States. Most FSIS residue data are for chemicals that food animals are likely to be exposed to, such as veterinary pharmaceuticals and pesticides.

Residue data for animal health drugs that are administered for therapeutic or production purposes were reviewed by the Panel but not addressed in this report because these drugs are administered purposefully; however, there were instances in which the FSIS animal drug residue database contained pharmaceuticals that have been measured in DTRW in California (Anderson et al., 2010). For example, residue data for ciprofloxacin, diclofenac, ketoprofen, sulfamethoxazole, and erythromycin were identified in the FSIS screening process, but were not necessarily confirmed as residue violations, and are summarized later in this chapter.

Residue data within FSIS's pesticide and trace element datasets represent exposures from all sources (air, feed, water, soil) and geographic regions within the United States. The residue data represent the *sum lifetime accumulations* of residue, again from all sources. That is, one would expect that environmental exposures to xenobiotic chemicals would have varied substantially across the sample set and that water sources and quality would have also varied greatly in the sampled animals. Sources of residues cannot be discerned from the data.

For chemicals for which no statutory tolerance is defined, the FSIS employs a "minimum level of applicability" (MLA) concept as a decision point. MLAs are the lowest concentrations of residue to have "been validated to be accurately and consistently reported by its testing method" (Morrison, 2015). For pesticides with established tolerances, FSIS sets the MLA at one-half the tolerance, but uses the tolerance value for regulatory decision making. The tolerance is the maximum allowable concentration of a marker residue in edible animal tissues.

Concentrations of analytes exceeding established tolerances are violative, and carcasses are considered adulterated. If a carcass contains a chemical residue for which there is no established tolerance, then the concentration of the residue must exceed the MLA for regulatory action to occur. MLAs are established to prevent high rates of false-positive samples, and to ensure a high degree of confidence that condemnations are based on solid evidence. As analytical capabilities improve, limits of quantification generally decrease; in such cases, the FSIS reserves the right to lower or increase MLAs as appropriate. MLAs are not health-based benchmarks but are generally conservative with respect to health effects because of the low limits of detection achieved by modern analytical instrumentation.

Pesticide residue data from approximately 4,300 samples analyzed by the FSIS between October 2015 and April 2017 are summarized in **Appendix 5-E**. A total of 108 analytes, including 44 of the EPA's "high" and "highest" priority chemicals were tested in edible tissues collected at slaughterhouses across the United States. Results are summarized with the MLAs, the octanol-water coefficient (log K_{ow} values, which serve as indicators of bioavailability [FSIS, 2017]), and the numbers of observations above the MLA noted during the sampling period. The data shows that the detection of pesticide residues above MLA concentrations in domestically produced livestock is infrequent. Again, pesticide residues measured in edible tissues of food animals represent *lifetime* accumulations from all xenobiotic sources (e.g., feed, water, air). During the 18-month period, 52 pesticide residues, representing 5 compounds (pentachlorobenzene, piperonyl butoxide, chlorothalonil, 1-napthol, and fipronil sulfide) were greater than their respective MLAs. Assuming that each incident was from a different animal, the total MLA exceedance was about 1.2 percent, but was less for a specific xenobiotic (0.4 percent for pentachlorobenzene).

Comparable rates of MLA exceedances have been documented for pesticides in sheep and goats in other developed countries, such as Australia (Adams et al., 1997). Tolerances of drug residues in meat products are established assuming a *lifetime* of *daily* exposures to foods containing residue concentrations at tolerance values. Assuming random distribution and using a very high exposure rate of 1.2 percent (across all screened compounds), the probability of a single consumer encountering an animal product containing residue concentrations at the MLA on three consecutive days is 1.7×10^{-6} or roughly 2 in 1 million[31]; the probability of encountering violative residues for 10 consecutive days would be roughly 1 in 10-million trillion[32].

31 $(0.012)^3 = 0.00000173 = 2 \times 10^{-6}$.

32 $(0.012)^{10} = 6.19 \times 10^{-20} \approx 1 \times 10^{-19} = 1/(1\times10^7)\cdot(1\times10^{12}) = 1/(10 \text{ million})\cdot(1 \text{ trillion})$.

FSIS residue data indicated that pharmaceuticals (ciprofloxacin, diclofenac, erythromycin, ketoprofen, sulfamethoxazole) at measurable concentrations in tertiary water produced in California were rarely present in meat sampled across the United States (Anderson et al., 2010). For example, during the 18-month FSIS study, more than 14,000 tissues were screened, and a total of 45 tissues contained ciprofloxacin, diclofenac, erythromycin, ketoprofen, or sulfamethoxazole screening analytical responses greater than their respective MLAs. Three of the five pharmaceuticals (diclofenac, ketoprofen, and sulfamethoxazole) were responsible for all instances MLA exceedances; therefore, the FSIS conducted further assessments of the positive tissues and concluded that diclofenac residues could not be confirmed. Confirmatory analyses verified that sulfamethoxazole and ketoprofen were present in a couple of the screened tissues, and the tissues were confirmed as violative. Collectively, after confirmatory testing, only a few of the 45 tissues identified by the screening assay had residues that actually exceeded an MLA.

The Animal Medicinal Drug Use Clarification Act (AMDUCA) of 1994 allows veterinarians to prescribe drugs not otherwise labeled for food animals in an off-label manner; however, the veterinarian is responsible for ensuring that drug residues do not remain in meat. Given the relatively sensitive assay used and the very low concentrations of these compounds in DTRW, the possibility of DTRW contributing to residues greater than an MLA is very low.

Trace element MLAs and residue levels in food animals in the United States are summarized in **Table 5-1**. Although the FSIS collects trace element data and has established analytical MLAs for each analyte, no regulatory action is taken in instances where trace element residues exceed MLAs.

This is because action levels have not been established for trace elements in food animals in the United States and debate continues on how they should be established. And, because many trace elements are also essential nutrients, the U-shaped dose response curves for animal health complicates the risk assessment process because both trace element deficiencies and excesses are associated with adverse physiologic endpoints.

Table 5-1. Trace Element Levels in Meat within the Food Supply in the United States

Element	FSIS Trace Element Analysis							
	MLA[A]		n[B]	Samples > MLA (n) Oct 6, 2015 to Apr 19, 2017[C]				
	Level	Unit		Bovine	Porcine	Poultry	Caprine	Ovine
Al	24	mg/kg	2,405	0	0	0	0	0
Ba	3.6	mg/kg	2,455	0	0	0	0	0
B	4.8	mg/kg	2,455	1	0	0	0	0
Cd	10	µg/kg	2,410	1	0	1	0	0
Cr	3.6	mg/kg	2,437	0	1	0	0	0
Co	25	µg/kg	2,448	2	0	0	0	0
Cu	3	mg/kg	2,447	1	0	0	0	0
Fe	30	mg/kg	2,437	384	6	2	0	0
Mb	50	µg/kg	2,445	8	1	20	0	0
Mn	200	µg/kg	2,454	140	4	4	0	0
Ni	6	mg/kg	2,455	0	0	0	0	0
Pb	25	µg/kg	2,390	2	0	0	0	0
Se	500	µg/kg	2,421	3	6	1	0	0
Sr	3	mg/kg	2,437	0	0	0	0	0
Tl	50	µg/kg	2,365	0	0	0	0	0
V	3.6	mg/kg	2,455	0	0	0	0	0
Zn	30	mg/kg	2,455	743	100	87	0	0

[A] Minimum Level of Applicability, FSIS (2016).

[B] Total number of samples analyzed.

[C] Data from FSIS (n.d.).

Acronyms: MLA = Minimum level of applicability. mg/kg = milligram per kilogram. µg/kg = microgram per kilogram.

Finally, numerous trace element interactions exist in which the presence of high or low levels of one element may mitigate or exacerbate the toxicity—or deficiency—of a second element. FSIS data consistently demonstrates that the background levels of trace elements of most concern (lead, cadmium, chromium, strontium, and vanadium) rarely exceed MLA values in commercially produced animals. However, home-raised animals, which generally have access to a diverse array of structures, feeds, and contaminants, may harbor higher levels of some trace elements (Bautista et al., 2014). The FSIS data also shows that concentrations of nutritionally required macro-trace elements such as iron, manganese, and zinc, which are often ingredients in trace-element supplements used in animal feed, commonly exceeded MLA values. These residues, however, are not considered to be of toxicological significance to people and are not regulated.

The FSIS also surveys the meat supply in the United States for non-pesticide xenobiotics. For example, recent surveys of highly bioaccumulative chemicals, including polychlorinated dioxins and furans (n = 17) and PCBs (n = 3 PCBs) (Lupton et al., 2017), and polybrominated diphenyl ether flame retardants (PBDEs; n = 7) (Lupton and Hakk, 2017), in more than 500 beef cattle, swine, and poultry carcasses demonstrated that: (1) tissue concentrations in food animals are extremely low for dioxins (median

ΣTEQ[33] = 0.03 to 0.38 pg/g lipid[34] across production classes) and brominated flame retardants (BFRs) (median Σ of total PBDEs = 105 to 526 pg/g lipid across production classes); and (2) dioxin and BFR residue concentrations in food animals continue to decline relative to concentrations measured in the 1990s and the first decade of the 2000s.

Again, the measured residue values represent lifetime accumulations for dioxins and BFRs from all sources, including water. For both dioxins and BFRs, feed is estimated to contribute more than 80 percent of the body burden of dioxins in cattle (Lorber et al., 1994); therefore, water represents a minor exposure pathway.

Finally, it should be noted that regulatory agencies measure chemical residues in raw products even though residues may decompose during storage (i.e., β-lactam antibiotics are unstable even at temperatures of -20 °C) or may be lost during cooking through decomposition or via drippings from meat (Petroske et al., 1998; Planche et al., 2017). For highly lipophilic xenobiotics, the trimming of fat from meat prior to cooking also will significantly reduce residue intakes. As such, residue concentrations in raw meat products typically represent worst-case scenarios with respect to consumer exposure estimates.

5.3.3 Investigating Clusters of Violative Residues

The FSIS, in cooperation with the FDA and (when appropriate) the EPA, has a mechanism for investigating clusters of high or violative residues (FSIS, 2017). Under its Tier 3 testing program, FSIS may direct resources that "encompass targeted testing at a herd or flock level. A targeted testing program designed for livestock or flocks originating from the same farm or geographic region may be necessary on occasion to determine the level of exposure to a chemical or chemicals."

Tier 3 testing encompasses both veterinary drugs and environmental contaminants that may be of human food safety concern. Follow-up testing programs after elevated residue levels are detected has been used to find and eliminate several dioxin sources that have contributed to high dioxin burdens in exposed animals, including wood treated with polychlorinated phenol (PCP), which was once used in livestock corrals and feeders; ball clay containing dioxin, which was used as an anti-caking agents in feed; and mineral supplements (Lupton et al., 2017). Because the FSIS samples animal products from every geographic region of the United States, regional spikes or sustained increases in violative residues can be investigated.

In other words, if DTRW given to animals led to an increase in residue levels or violations in California, the infrastructure within the FSIS residue monitoring program would investigate the causes of those violations.

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33 ΣTEQ is the summed Toxic Equivalencies for the 17 polychlorinated dioxins, furans, and polychlorinated biphenyls (PCBs) measured. A toxic equivalency adjusts the potency of each dioxin congener to that of the most toxic dioxin congener: 2,3,7,8-tetrachloro-dibenzodioxin. For tissue residues, toxic equivalencies are used to normalize differing concentrations of numerous congeners into a single, usable value (see Van den Berg et al., 2006).

34 pg/g lipid = picograms per gram = parts per trillion.

5.4 Approach Used to Assess Chemical Risks to Animal Health

Typically, water quality is not a pressing issue for most modern livestock production systems. Based on previous experience, animal producers generally assume sufficient water quality in the absence of known water quality problems.

5.4.1 Animal Health and Safety

For some types of livestock production, water sources may never change on a farm and water quality remains consistent throughout production cycles, while others rely on more varied sources. Monogastric animals such as such as swine and poultry are generally given potable water, which may be sourced from municipal or on-farm wells. In California, approximately 45 percent of water used for livestock is from groundwater sources (Maupin et al., 2014). Meanwhile, ruminant grazing animals such as cattle and sheep are more likely to drink surface water from rivers and streams, shallow well water collected into holding tanks, and/or stock tanks that collect runoff. The water quality in these systems may vary considerably within and across production cycles. Given the degree of variability across livestock production systems, the absolute quality of water used by producers varies widely and cannot easily be generalized, except to say that the most water used for livestock would be qualitatively assessed as safe by veterinarians. In other words, the known causes of livestock disease or inefficiency are not *commonly* associated with water quality, even when that water would be considered poor quality for human use.

Historically, *chemical* water quality for livestock has been described in terms of the propensity of water to cause overt acute or chronic disease in the animals. Chemically mediated maladies fall into three main categories:

1. Disease caused by microbial toxins, such as cyanotoxins released by blue-green algae (cyanobacteria). Cyanotoxins, rather than the bacteria themselves, are the mediators of syndromes associated with cyanobacteria (Wood, 2016).
2. Disease caused by naturally occurring elemental chemicals (such as arsenic, fluoride, sulfates) or their oxides present in waters from geologic sources.
3. Poisoning from chemicals of human-caused origin, including from nitrates/nitrites used as fertilizers (Olkowski, 2009), chemicals from industrial water contamination (Edwards, 1989), and chemicals produced by water treatment processes (Tofant et al., 2010).

Collectively, livestock poisonings *generally* are characterized by the contamination of water at parts per million (ppm; mg/L) levels or greater. In considering the risks of using DTRW in livestock production, the Panel was aware that specific chemicals of potential concern were present nearly always in much lower concentrations, ranging from parts per trillion (ppt; ng/L) to parts per billion (ppb; µg/L) (Anderson et al., 2010; MWH, 2007). Risks associated with such low levels of chemicals are never acute, but the chronic consequences of such exposures are difficult to measure. The chronic toxicological endpoints (and doses required to elicit those endpoints) of most chemicals in DTRW are not sufficiently characterized in livestock for formal risk assessment (CCME, 1999).

Animal and veterinary scientists have been reluctant to establish firm guidelines for trace contaminants in water used for livestock because livestock production is not uniform and conducting unambiguous

species-specific toxicology is costly. Therefore, water quality guidelines for livestock have been established mostly for chemicals that cause outright animal toxicity or severe economic loss for animal producers (Carson, 2000; Morgan, 2011). Livestock water quality guidelines for most countries, if available, are provided for crude endpoints, such as total dissolved solids (TDS) or salinity, which may affect how much water an animal will drink, and macro-level chemical or bacterial contamination.

In evaluating whether DTRW would be safe for livestock watering, the Panel assumed that DTRW may contain naturally occurring and synthetic chemicals, pesticides, and pharmaceuticals of a variety of potencies. In addition, the concentration of each chemical in water may differ by the source and method of processing DTRW. Although many chemicals have been measured in surface water (Kolpin et al., 2002; MWH, 2007) and groundwater (Barnes et al., 2008) in the United States, relatively little data is available that documents the concentrations of chemicals in DTRW. The Panel used data from three primary sources, as noted in **Chapter 3**.

The State Water Resources Control Board commissioned an Expert Panel to provide recommendations for monitoring CECs in recycled water. Anderson et al. (2010) reported the 90th percentile concentrations of relevant chemicals in DTWR (Tables 5.1, 5.2, and 5.3 of Anderson et al., 2010) that were useful to this Panel. In addition, Guo et al. (2010) reported data on chemical concentrations in wastewater effluents contributing to the Santa Ana River in Southern California. This watershed is heavily influenced by tertiary-treated water and, in some cases, the water concentration data were used by the current Panel. Finally, an extensive study conducted by the City of San Diego and the Aqua 2030 Research Center (MWH, 2007) described the concentrations of many chemicals in tertiary waters before they enter advanced water treatment.

To assess potential health effects of DTRW to livestock, concentrations of specific chemicals in tertiary treated wastewater were first compared with Canadian (CCME, 1999) estimates of allowable levels, or benchmarks, of the same chemicals in livestock drinking water. These comparisons indicated whether DTRW would be expected to contain concentrations of a given chemical that approached guideline concentrations. The Panel found few formal risk assessments available for trace-level chemicals in livestock water supplies. However, risk assessments on approximately 64 potential chemicals in livestock drinking water were conducted by the Canadian Council of Ministers of the Environment (CCME); the water quality guidelines developed from these risk assessments are available online (CCME, 1999) and were extensively used by the Panel. Data requirements and calculations used by the CCME to establish livestock drinking water quality guidelines are summarized in **Chapter 3.**

Table 5-2 summarizes chemicals that are often associated with decreased water quality to support livestock production and concentrations of chemicals thought to be safe for livestock. The information in this table is not exhaustive and provides context for water quality issues that are important to animal producers and veterinarians. Notably, most chemicals associated with poor water quality are elemental metals and are of geologic origin rather than manmade.

Table 5-2: Acceptable Upper Concentration Limits for Chemicals in Livestock Drinking Water

Compound	Upper Concentration Limits for Livestock	
	United States (mg/L)	Canada (mg/L)
Nitrate + Nitrite	100	100
Nitrite	10	10
Sulfate	500	1,000
Total Dissolved Solids	10,000	3,000
Aluminum	5.0	5
Arsenic	0.2	0.025
Beryllium	--	0.1
Boron	5	5
Cadmium	0.05	0.08
Calcium	--	1,000
Chromium	1.0	0.05
Cobalt	1.0	1
Copper	0.5	--
Fluoride	2.0	--
Lead	0.05	0.1
Mercury	0.01	0.003
Molybdenum	--	0.5
Nickel	--	1
Selenium	0.05	0.05
Uranium	--	0.2
Vanadium	0.1	0.1
Zinc	24	50

Adapted from Soltanpour and Raley (1999), Carson (2000), Morgan (2011), and CCME (1999).

Note: Data listed are expressed as “mg/L” (milligrams/liter; parts per million). Concentration data in later tables, however, are expressed in units of “ng/L” (nanograms/liter; parts per trillion). To convert mg/L to ng/L, multiply by 1,000,000 (1 mg/L = 1,000,000 ng/L).

Table 5-3 compares Canadian livestock drinking water guideline concentrations and chemicals measured in DTRW from California. In no case was the concentration of chemical in DTRW greater than guideline concentrations. Concentrations of most chemicals in DTRW were indistinguishable from zero and/or were much less than guideline values, indicating a high margin of safety.

Table 5-3: Canadian Livestock Drinking Water Quality Guidelines for Chemicals Compared to Chemical Concentrations Measured in Disinfected Tertiary Recycled Water in California

Compound	Guideline Concentration[a] (ng/L)	DTRW Water Concentration (ng/L)	Reference[b]
1,1,2-Trichloroethane (TCE)	50,000	ND[c]	B
1,2-Dichloroethane	5,000	331	B
Aldicarb	11,000	ND	B
Aluminum	5,000,000	11,600	B
Arsenic	25,000	2,180	B
Atrazine	5,000	5[d]	C
Atrazine	5,000	ND to 1	B
Beryllium	100,000	ND	B
Boron	5,000,000	379,000	B
Bromacil	1,100,000	--	--
Bromoxynil	11,000	--	--
Cadmium	80,000	ND	B
Calcium	$1x10^9$	--	--
Captan (ethanethiol, ethyl mercaptan)	13,000	--	--
Carbaryl	1,100,000	ND	B
Carbofuran	45,000	ND	B
Chlorothalonil	170,000	--	--
Chlorpyrifos	24,000	--	--
Chromium-hexavalent	50,000	--	--
Chromium-trivalent	50,000	--	--
Cobalt	1,000,000	--	--
Cyanazine	10,000	<20[e]	C
Deltamethrin	2,500	--	--
Dibromochloromethane	100,000	360	B
Dicamba	122,000	ND	B
Dichlorobromomethane	100,000	--	--
Dichloromethane (methylene chloride)	50,000	276	B
Diclofop-methyl	9,000	--	--
Dimethoate	3,000	--	--
Dinoseb	150,000	ND	B
Ethylbenzene	2,400	ND	B
Glyphosate	280,000	--	--
Hexachlorobenzene	520	ND	B
Hexachlorocyclohexane (lindane)	4,000	ND	B
Lead	100,000	ND	B
Mercury	3,000	--	--
Methylchlorophenoxyacetic acid (MCPA)	25,000	ND	B
Metolachlor	50,000	--	--
Metribuzin	80,000	--	--

Compound	Guideline Concentration[a] (ng/L)	DTRW Water Concentration (ng/L)	Reference[b]
Molybdenum	500,000	--	--
Nickel	1,000,000	5,810	B
Nitrate + Nitrite	$1x10^8$	45,000	B
Nitrite - NO_2-N	$1x10^7$	--	--
Phenols (mono- & di-hydric)	2,000	--	--
2,4-Dichlorophenoxyacetic acid (2,4-D)	100,000	ND	B
Picloram	190,000	ND	B
Selenium	50,000	3,310	B
Simazine	10,000	ND	B
Sulfate	$1x10^9$	$2.41x10^8$	B
Tebuthiuron	130,000	--	--
Tetrachloromethane (carbon tetrachloride)	5,000	ND	B
Toluene	24,000	ND	B
Total dissolved solids (TDS)	$3x10^9$	$9.98x10^8$	B
Triallate	230,000	--	--
Tribromomethane (bromoform)	100,000	ND	B
Tributaltin	250,000	--	--
Trichloromethane (chloroform)	100,000	1,340	B
Tricyclohexyltin	250,000	--	--
Trifluralin	45,000	ND	B
Triphenyltin	820,000	--	--
Uranium	200,000	--	--
Vanadium	100,000	3,300	B
Zinc	$5x10^7$	29,100	B

[a] From CCME (1999).

[b] References for the tertiary water concentrations for indicated chemicals are as follows: B = MWH (2007); C = Guo et al. (2010).

[c] Not Detected; Method limits of detection vary by analyte and are reported in the source literature.

[d] Maximum concentration in wastewater treatment plant effluents contributing to the Santa Ana River Watershed in Southern California.

[e] Cyanazine was not detected in any of the wastewater treatment plant effluents contributing to the Santa Ana River Watershed in Southern California.

The Panel referred to human drinking water guidelines for chemicals not included in the Canadian livestock drinking water guidelines, and also relied on a report by Anderson et al. (2010), which summarized known concentrations of CECs in DTRW with a variety of benchmark values obtained from regulatory agencies and literature. The Panel assumed that benchmarks for human health would be fully protective against acute and chronic effects for the classes of livestock defined in this report.

The Panel assumed that human drinking water benchmarks are more conservative than those for livestock drinking water because the values used for humans typically are calculated with a larger safety factor than for livestock. In other words, if concentrations of CECs in DTRW were lower than the corresponding benchmark for human drinking water, then the DTRW should be safe for livestock use. Anderson et al. (2010) provides details on how benchmark values for human drinking water are derived.

Concentrations of chemicals reported to be in DTRW with benchmark values reported by Anderson et al. (2010) are shown in **Table 5-4**. Chemicals selected for inclusion in the table were based on:

- Existing reports of concentrations in DTRW (or tertiary water) from California.
- Availability of a human or livestock water guideline.
- Availability of FSIS-food animal tissue residue data (see **Section 5.4.2**).
- General interest as a member of an endocrine disrupting compound.

Concentrations of chemicals in DTRW presented in the table represent high estimates (90th percentiles) reported by Anderson et al. (2010) or other reports (Ensminger et al., 2013; Guo et al., 2010); therefore, the exposure estimates are higher than likely exposures. A review of **Table 5-4** indicates that in no case except for triclosan and β-estradiol did concentrations of target chemicals in DTRW approach human or livestock guideline values. The range of human exposure guideline values for each chemical is noteworthy; variances in guideline values often span several orders of magnitude, reflecting different assumptions and safety factors used during the risk assessment process. Exposures to triclosan and 17-β-estradiol in DTRW could possibly represent risks to livestock consuming such water, having “low” safety margins of 0.7 and 0.1, respectively. Low safety margins were calculated by dividing the lowest human drinking water guidance value reported (ng/mL) by the 90th percentile concentration in DTRW (ng/mL); safety margins below 1 suggest guidance values could be exceeded with the use of DTRW.

Table 5-4. Livestock Safety Margins for COPCs for Livestock Watered with DTRW

Compound	Water Content *ng/L*	Human Exposure Guidelines[B,C]							Safety Margin[D]		Canadian Livestock[O] *ng/L*
		PNEC *ng/L*	$PNEC_{DW}$ *ng/L*	DWG *ng/L*	DWEL *ng/L*	PGV *ng/L*	LGV *ng/L*	ADI or RfD *ng/kg/D*	Lowest	Highest	
Triclosan[A]	485			350	2,600,000		500,000	75,000	0.7	7,429	
17β-Estradiol[A]	8	0.9[E]		180	1,800			50	0.1[E]	225	
Bifenthrin[F]	20	105,000[H]						15,000[G]	5,250	5,250	
Firpronil[J]	418	1,400[H]						200[I]	3	3	
Carbaryl[K]	22	700,000[H]						100,000[L]	31,818	31,818	1,100,000
Diuron[M]	136	1,800		30,000		7,000	18,000	3,000	13.2	221	
Atrazine[M]	5			40,000	3,000		2,000	35,000[N]	400	8,000	5,000
Ciprofloxacin[A]	100		23,000	250,000					230	2,500	
Diclofenac[A]	230			1,800	2,300,000				7.8	10,000	
Ketoprofen[A]	43			3,500					81	81	
Sulfamethoxazole[A]	1400		1,900,000	35,000	18,000,000	440,000			25	12,857	
Erythromycin[A]	113	4,900	580,000	18,000				700	43	5,133	
PFOS[A]	90	200				500			2.2	5.6	
PFOA[A]	28	1,100				5,300			39	189	
Bisphenol-A[A]	286	350,000		200,000	1,800,000		300,000	50,000	699	6,294	
TCEP[A]	688	2,500		1,000			77,000		3.6	112	

[A] Disinfected tertiary recycled water concentration, 90th percentile Measured Environmental Quantities; Anderson et al. (2010).

[B] From Appendix J of Anderson et al. (2010).

[C] PNEC = Predicted No Effect Concentration. DWG = Drinking Water Guideline. DWEL = Drinking Water Equivalent Level. PGV = Provisional Guidance Level. LGV = Lowest Guideline Value.

[D] Safety Margin for using DTRW for livestock watering is calculated as the Guideline Value ÷DTRW content; values <1 suggest high exposure.

[E] See page 32 of Anderson et al. (2010) for a discussion of the uncertainties with respect to modeling lifetime cancer risks to people for estradiol.

[F] Median surface water concentration of bifenthrin in the Sacramento cohort of samples, the highest (P>0.0002) median concentration of bifenthrin measured in any other cohort (Ensminger et al., 2013).

[G] From EPA (1988).

[H] Calculated from the RfD as described in Appendix J (page J-22) by Anderson et al. (2010). That is, PNEC = [(RfD x 70)x0.2]÷2 L, where the RfD is in mg/kg, human body size is 70 kg, the relative contribution factor is 0.2, with 2 L per day water consumption.

[I] Chronic RfD, from Federal Register (2007).

[J] Mean maximum fipronil concentration of surface waters (n = 24) reported in Supplementary Table 6 of Ensminger et al. (2013).

[K] Mean concentration of carbaryl in California surface waters (n = 2900 measurements by California State and Local Agencies); from CDPR (2017).

[L] From EPA (2007).

[M] The maximum concentration measured in waste water treatment plant effluent in the Santa Ana River Watershed as reported by Guo et al. (2010)

[N] From EPA (1987).

[O] From CCME (1999).

The Panel considered, however, that for 17-β-estradiol, the PNEC of 0.9 ng/L (ppt) is substantially less than estradiol present in calf muscle (110 ng/kg), liver (70 ng/kg), and fat (120 ng/kg), and substantially less than β-estradiol measured in eggs (30 to 220 ng/kg) (Hartmann et al., 1998), which strongly suggests that drinking water contributions to estrogen burdens in food animals are low compared to the animals' internal estrogen production. Further, the oral bioavailability of β-estradiol in mammals is poor, because estrogens are rapidly cleared by first-pass conjugation in the intestine and liver (Kuhl, 2005). Water sources of estradiol would not negatively impact animal physiology relative to internal estrogen production.

Anderson et al. (2010) discusses difficulties and differences among approaches of regulatory agencies when estimating safe human lifetime exposures to exogenous β-estradiol sources. Low estimates of safe exposures are based on cancer endpoints from rodent studies, while higher estimates of safe exposures are based on non-cancer endpoints. The Panel did not consider cancer endpoints to be appropriate for food animals that are harvested just before, or at the end of, rapid growth. Further, estradiol is an active ingredient in several FDA-approved subcutaneous implants used to improve growth in cattle (Preston, 1999). Finally, the estrogenic activity delivered to all livestock species via phytoestrogens in feed, such as soybean meal, alfalfa, or clover, (Mostrom and Evans, 2011) dwarfs the estrogen that theoretically would be delivered to livestock via DTRW.

The antiseptic triclosan was the other chemical that exceeded a human drinking water guideline value in DTRW. The Panel noted, however, that triclosan drinking water guideline values varied by approximately three orders of magnitude and that triclosan is a common ingredient in human personal care products, including toothpaste, at concentrations of up to 0.3 percent (3,000 ppm; Dhillon et al., 2015). Triclosan has not been banned by regulatory agencies in personal care products for people. Animal exposures through residues in highly contaminated DTRW would be minimal relative to daily human exposures; therefore, the Panel concluded that triclosan residues in DTRW are unlikely to reach concentrations that would negatively affect livestock.

5.4.2 Human Health and Safety: Magnitude and Safety of Residues

To determine whether chemicals in DTRW might have negative health effects on people consuming meat and eggs, the Panel also addressed the safety of food products from animals that are raised exclusively on DTRW. Because hundreds of chemical residues may be present in DTRW at trace levels, it was necessary to take a reductionist approach. The Panel considered chemicals in the EPA's NPDWR and CCL 4, and chemicals on California's drinking water notification list in conducting this assessment.

The Panel recognized that the solubility of chemicals is an important variable when determining the risk for residue accumulation. For example, polar (charged) chemicals that dissolve easily in water are not likely to bioaccumulate in food animals because they tend to be metabolized and/or excreted fairly quickly and have a short half-life in the animal after absorption (see **Appendix 5-G** for a list of known half-lifes for DBPs). Many common water-soluble personal care products, antibiotics, human pharmaceuticals, and modern pesticides are therefore not likely to accumulate in food animals. Meanwhile, non-polar (neutral) chemicals are lipophilic, meaning they are soluble in fat, and have potential to bioaccumulate in the animal if they are in the animals' diet or water. Examples of lipophilic environmental contaminants include dioxins, dioxin-like furans, polychlorinated biphenyls, halogenated

flame retardants, and phased-out pesticides, such as dichlorodiphenyl trichloroethane (DDT) and chlordane. However, lipophilic chemicals often are removed by sedimentation during wastewater treatment through particulate binding (Knauer et al., 2017; Ratola et al. 2012). Surveys of tertiary treated wastewaters have not found strong evidence for highly lipophilic molecule transfer (Ratola et al., 2012); therefore, the likelihood of lipophilic CECs accumulating in animals raised on DTRW water is low. Other organic pollutants, especially those that are ionized or resistant to bacterial metabolism, such as perfluorinated compounds, may not be removed efficiently during wastewater treatment; livestock that drink DTRW could be exposed to these xenobiotics.

In an effort to understand the incidence and magnitude of background levels of organic pollutants in animal feed, the Panel reviewed pesticide residue data for 108 compounds that was collected as part of the FSIS National Residue Program for Meat, Poultry and Eggs (FSIS, 2017; **Appendix 5-E**). Data collected over 18 months—and representing more than 4,000 samples from many classes of food animals—were reviewed to ascertain the baseline residue levels in tissue from all sources, including water, feed, and air. On average, based only on preliminary, non-confirmed, multi-residue screening data, a permethrin pesticide residue was detected in 1.9 percent of samples (82 of 4,347 samples); the highest detection rate for permethrin was 19 percent. Of samples containing detectable permethrin residue, only three (of 4,343 samples, or 0.07 percent of total) exceeded the MLA of 25 μg/kg. For permethrin, the high detection rate did not indicate a high rate of MLA exceedance.

Most samples that were tested had non-detectable residue for any given chemical. Across all pesticides, pentachlorobenzene was the residue that most frequently exceeded its MLA using the non-confirmatory screening assay, with 18 of 4,291 samples (0.4 percent) containing estimated concentrations of 10 μg/kg or greater. From these data, the Panel concluded that the baseline level of residues is not a general concern. Had there been residues detected and confirmed at high percentages, it would suggest that, on average, the addition of residue from DTWR could increase residue violation rates.

The Panel further calculated theoretical residue concentrations in meat and egg products for a diverse group of chemicals. For these calculations, the Panel was conservative in its approach using “worst case” assumptions that would tend to exaggerate exposures to chemicals and the concentrations of residues in meat and eggs. For example, in formulating worst-case scenarios for residue calculations, the Panel set the following (albeit unrealistic) conditions:

- The lowest ADI or reference dose (RfD) available was used to assess human safety with respect to potential residue intake.
- The 90th percentile concentration of a chemical measured in DTRW was used when available; otherwise, concentrations measured in untreated surface waters were used.
- For compounds that do not accumulate in tissues, the Panel chose to partition the complete 24-hour intake of a chemical into skeletal muscle (meat) or the complete 48-hour intake of a residue into an egg. Consequently, the Panel assumed that metabolism and/or excretion did not occur in the 24 to 48 hours before harvesting an edible product.
- For compounds that have the potential to accumulate, such as PFOS, extended exposure periods were used to allow for an exaggerated residue accumulation.

In **Table 5-5**, hypothetical worst-case residue scenarios in cattle are shown for a variety of chemicals that may be present in trace amounts in DTRW. The table clearly shows that the amount of residue eaten by a consumer, even in a worst-case scenario, is a tiny fraction of the ADI for the given residue. Calculated margins of safety (the ADI ÷ calculated residue intake) typically were hundreds to millions. In other words, for a margin of safety of 100, a person would have to eat 30 kg (66 lbs) of beef in a single meal to be exposed to an ADI of a chemical.

Nevertheless, using a series of assumptions with specific xenobiotics across several chemical classes, the Panel evaluated theoretical, worst-case exposures of food animals to chemicals that might be present in DTRW and considered later ingestion of those residues by people after eating meat or eggs. Using worst-case residue scenarios, theoretical human intakes were compared to human ADIs derived from regulatory or literature sources.

Table 5-5. Worst-Case Animal and Human Exposures to Chemical Residues Present in DTRW, Using Beef as the Example

Chemical	Human ADI or RfD *mg/(kg·d)*	DTRW Concentration *µg/L*	Canadian Livestock Water[A] *µg/L*	Beef Animal		FSIS Tolerance or MLA *µg/kg*	Human Intake		Margin of Safety[F]
				Intake[B] *µg*	Muscle Residue[C] *µg/kg*		Total[D] *µg/d*	Body Wt. Basis[E] *ng/(kg·d)*	
Arsenic	0.003	10	25	660	2.80	NA	0.839	14.0	215
Atrazine	0.0001	0.005	5	0.330	0.0014	10	0.00042	0.007	14,300
Bifenthrin	0.015	0.020		1.32	0.0056	5	0.00168	0.028	536,000
Bisphenol-A	0.004	0.286		18.9	0.0800	NA	0.024	0.400	10,000
Boron	0.130	275	5,000	18,200	77	NA	23	385	338
Carbaryl	0.100	0.022	1,100	1.50	0.0062	25	0.002	0.031	3,250,000
Ciprofloxacin	0.006	0.100		6.60	0.0280	100	0.008	0.140	42,900
Diclofenac	0.0007	0.230		15.2	0.0643	5	0.019	0.322	2,180
Diuron	0.003	0.136		9.00	0.0380	80	0.011	0.190	15,800
Erythromycin	0.0042	0.113		7.50	0.0316	50	0.009	0.158	26,600
Estradiol	0.00005	0.008		0.528	0.0022	NA	0.00067	0.011	4,470
Fipronil	0.002	0.300		19.8	0.0839	5	0.025	0.419	477
Ketoprofen	0.0011	0.043		2.80	0.0120	5	0.004	0.060	18,300
PFOA	0.0015	0.028		12.9	0.0548	NA	0.016	0.274	5,470
PFOS	0.00015	0.090		3,208	13.6	NA	4.078	68	2
Sulfamethoxazole	0.0100	1.593		105	0.89	50	0.267	4.5	2,200
TCEP	0.022	0.688		45.4	0.192	NA	0.058	0.962	22,900
Triclosan	0.0500	0.485		32.0	0.136	NA	0.041	0.700	73,700

[A] From CCME (1999).

[B] Calculated by: DTRW Concentration x 66" (µg/L x L = µg). For non-accumulative chemicals, assume a 24-hour intake and consumption of 66 L of DTRW per day. The entire chemical intake was used as the basis of residue concentration and human exposure; metabolism/excretion was not considered. Three chemicals were considered to be accumulative in cattle: (1) Sulfamethoxazole has a half-life of 12 hours in cattle; residue calculations were based on total intake for the 48-hour period prior to slaughter. (2) PFOS has a half-life of 165 days in cattle; residue calculations were based on intake during a 540-day grow-out period. (3) PFOA has a half-life of 19 hours in cattle; residue calculations were based on total intake for the 7-day period prior to slaughter.

[C] Calculated by "intake ÷ kg muscle" (µg ÷ kg = µg/kg); a 364-kg beef animal was assumed to have 236 kg of muscle.

[D] Total human intake calculated by "muscle residue x meat consumption" (µg/kg x kg/d = µg/d); meat consumption values were obtained from the FDA CVM (2016).

[E] Calculated by "total human intake ÷ 60 kg" (ug/d ÷ 60 kg = µg/(kg·d)).

[F] Calculated by "Human ADI or RfD ÷ human intake body wt. basis" ([mg/(kg·d) x 1,000,000 ng/mg] ÷ ng/(kg·d)].

Exposure estimates were based on a 364-kg beef animal, having 236 kg of edible muscle, consuming 66 L of DTRW per day. Human exposure estimates were calculated assuming consumption of 300 g of muscle (FDA, 2016) by a 60-kg person. Concentrations of chemicals in DTRW were obtained from Anderson et al. (2010) or other literature sources. The margin of safety is the ratio of the human acceptable daily intake for a chemical (on a ng/kg basis [mg/kg x 1,000,000 ng/mg]) and the estimated human intake on a body weight basis (ng/kg/d). Tolerances and MLAs used by the USDA FSIS of chemicals in beef muscle are shown for comparative purposes.

The calculated margin of safety for PFOS, however, was estimated at 2. The Panel noted that for PFOS, which has potential to accumulate, extreme assumptions were used. That is, for the purposes of ensuring conservatism in assessing human exposures, the Panel assumed that: (1) the entire lifetime consumption (540 days) of PFOS accumulated solely in skeletal muscle; (2) water intake was constant at 66 L/day across the lifetime of the animal, regardless of its size; (3) no excretion or metabolism of PFOS occurred; (4) PFOS concentration in DTRW was high (90th percentile); and (5) a small body weight of 360 kg (800 lbs.) was used relative to the 540-day grow out period (thus, tending to concentrate residues). Even with these biologically improbable assumptions, the PFOS intake was less than half of the ADI.

As shown in **Table 5-5**, residue accumulations in meat products from animals exposed to DTRW would not approach established tolerances or MLAs. The chemical residue that comes closest to an MLA is sulfamethoxazole, but again the Panel used conservative assumptions with respect to residue accumulation. For sulfamethoxazole, the Panel assumed that an entire daily intake accumulated in skeletal muscle only, with no metabolism or excretion, and a 90th percentile water concentration. Even with the conservative estimate of tissue residues, the FSIS MLA for sulfamethoxazole was 18 times greater than the worst-case residue.

Using worst-case scenarios for the accumulation of residues in eggs, shown in **Table 5-6**, also indicates a wide margin of safety with respect to ADIs or Reference Doses. The lowest margin of safety calculated by the Panel was for two naturally occurring elements, arsenic (14-fold) and boron (22-fold), and for PFOS (22-fold). Even if one assumes that 100 percent of each of these chemicals preferentially and specifically accumulates in eggs, one would still have to eat between 3.1 and 4.8 pounds of eggs per day to exceed acceptable regulatory agency levels.

Table 5-6. Worst-Case Animal and Human Exposures to Chemical Residues Present in DTRW, Using Eggs as the Example

Chemical	Human ADI or RfD *mg/(kg·d)*	DTRW Concentration *µg/L*	Canadian Livestock Water[A] *µg/L*	Hen Exposure		Human Intake		Margin of Safety[F]
				Intake[B] *µg*	Egg Residue[C] *µg/g*	Total[D] *µg/d*	Body Weight Basis[E] *ng/(kg·d)*	
Arsenic	0.003	10	25	3.20	0.128	12.8	213.0	14
Atrazine	0.0001	0.005	5	0.00160	0.000064	0.006	0.1	938
Bifenthrin	0.015	0.020		0.00640	0.000256	0.026	0.4	35,156
Bisphenol-A	0.004	0.286		0.092	0.00336	0.366	6.1	656
Boron	0.130	275	5,000	88.0	3.520	352	5,870	22
Carbaryl	0.100	0.022	1,100	0.007	0.000282	0.028	0.5	213,068
Ciprofloxacin	0.006	0.100		0.032	0.001280	0.128	2.1	2,813
Diclofenac	0.0007	0.230		0.074	0.00294	0.294	4.9	143
Diuron	0.003	0.136		0.044	0.00174	0.174	2.9	1,034
Erythromycin	0.0042	0.113		0.036	0.00145	0.145	2.4	1742
Estradiol	0.00005	0.008		0.0026	0.000102	0.0102	0.2	293
Fipronil	0.002	0.300		0.096	0.00384	0.384	6.4	31
Ketoprofen	0.0011	0.043		0.014	0.000550	0.055	0.9	1,199
PFOA	0.0015	0.028		0.009	0.00125[B]	0.125	2.1	717
PFOS	0.00015	0.090		0.029	0.00403[B]	0.403	6.7	22
Sulfamethoxazole	0.0100	1.593		0.510	0.0204	2.04	34.0	294
TCEP	0.022	0.688		0.220	0.00881	0.881	14.7	1,499
Triclosan	0.0500	0.485		0.155	0.00621	0.621	10.3	4,832

[A] From CCME (1999).

[B] Calculated by: "DTRW Concentration x 0.32" (µg/L x L = µg).

[C] Calculated by "[Intake" x 2] ÷ 50 g" ([µg x 2] ÷ 50 g = µg/g); 100 percent of the chemical intake during a 2-day period was assumed to be transferred to a 50-g egg; for PFOA and PFOS the egg residue assumed that 100 percent of the residue accumulated over a 7-day period was deposited into a single egg.

[D] Total human intake calculated by "Egg Residue x egg consumption" (µg/g x g/d = µg/d); egg consumption of 100 g/d were obtained from the FDA CVM (2016).

[E] Calculated by "[total human intake ÷ 60 kg] x 1000 ng/µg" ([µg/d ÷ 60 kg] x 1000 ng/µg = ng/(kg·d)).

[F] Calculated by "Human ADI or RfD ÷ human intake body wt. basis" ([mg/(kg·d) x 1,000,000 ng/mg] ÷ ng/(kg·d)].

Exposure estimates were based on a 1.9 kg-laying hen consuming 0.32 L of DTRW per day. Calculations assume that 100 percent of the chemical residue consumed by the hen during 48 hours was passed to the egg. Human exposure estimates were calculated assuming consumption of 100 g of eggs per day (FDA, 2016) by a 60-kg person. The margin of safety is the ratio of the human ADI for a chemical (on a ng/kg basis) and the estimated human intake on a body weight basis (ng/kg/d).

5.5 Conclusions

The Panel arrived at the following conclusions on the chemical safety of DTRW:

1. Documented incidents of human intoxication caused by the consumption of chemical residues in meat and eggs are rare and are mostly associated with historical or contemporary misuse of animal drugs that are purposefully given to animals in high doses.
2. Contemporary (the last 50 years) examples of human chemical intoxications in the United States (and other developed countries) caused by the consumption of chemical residues in meat are difficult to find in the literature and are likely extremely rare. When residues cause human intoxication, the toxic agent was usually given purposefully to animals. It is difficult to document human intoxications resulting from the exposure of food animals to contaminants in water.
3. Residues measured in animals at slaughter by federal regulators represent lifetime accumulations (the sum of metabolic clearance processes) for both rapidly and slowly cleared xenobiotic chemicals.
4. Residues measured in raw animal tissues by the FSIS represent maximum concentrations and do not account for losses that may occur during cooking (degradation, loss with fat drippings, or volatilization) or trimming (fat and connective tissue removal).
5. Residues of pesticides, trace elements, and environmental contaminants in carcasses from animals produced throughout the United States typically are well below levels considered to be safe for consumers.
6. The probability of a single consumer encountering an animal tissue containing residues meeting or exceeding tolerances or MLAs on consecutive days is remote, while the probability of a consumer encountering violative residues in meat during 10 consecutive days is infinitesimally low.
7. Contributions of chemicals in DTRW to body burdens of chemicals in food animals are believed to be low relative to other exposure sources (e.g., feed, soil, dust, air).

5.6 Recommendations

The Panel agreed that chemicals in DTRW are not likely to pose a significant threat to the health of non-dairy livestock given the low concentrations of chemicals in DTRW and the availability of human health-based benchmarks to evaluate the risk. Furthermore, the Panel found no evidence that meat and eggs from animals that are given DTRW as their sole drinking water source would pose an adverse health risk to people, because of: (1) the conservative nature of estimating the chemical concentrations in meat

and eggs; and (2) human health-based benchmarks, such as the acceptable daily intake, using well-established safety factors.

However, due to the lack of dose-response data for chemicals of concern in livestock animals, the Panel recommends that any **DTRW system that provides drinking water to livestock be required to develop and maintain targeted source control that complies with the National Pretreatment Program and includes technically based local limits to exclude concentrated industrial chemicals of concern.**

In addition, the Panel encourages the State Water Board to work with appropriate state agencies to develop appropriate recommendations for future monitoring efforts.

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PART 3: PANEL FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

- The Panel concludes that there is insufficient evidence to determine if using DTRW for non-dairy livestock watering is protective of the health of livestock and people eating food products from livestock.
- Accordingly, the Panel recommends additional uniform water recycling criteria in response to the requirements of AB 2071.
- The Panel suggests future research to determine how long-term use of DTRW for livestock watering will affect livestock health and the quality of livestock food products.

6.1 Introduction to Panel Conclusions and Recommendations

This chapter presents the Panel's conclusions and recommendations in response to the questions posed by the California Legislature and State Water Board. The Panel agreed that there is sufficient evidence that not all forms of DTRW are safe for non-dairy livestock watering. Therefore, the Panel recommends that DTRW delivered for livestock watering should be produced in accordance with the BMPs presented in this report to ensure the safety of people and animals.

6.2 Panel's Responses to Questions Posed by the Legislature

AB 2071 was approved by Governor Brown on September 28, 2014 and filed with the Secretary of State on September 28, 2014. AB 2071 posed the following question:

> *"… Whether the use of disinfected tertiary treated recycled water, as defined by Section 60301.230 of Title 22 of the California Code of Regulations, for the purpose of providing water to animals, would not pose a significant risk to public and animal health. If the state board determines that the use of disinfected tertiary treated recycled water for the purpose of providing water to animals would pose a significant risk to public or animal health, the state board shall establish uniform statewide recycling criteria for the use of disinfected tertiary treated recycled water for the purpose of providing water to animals. Except as provided in subdivision (c), if the state board determines that the use of disinfected tertiary treated recycled water for the purpose of providing water to animals would not pose a significant risk to public or animal health, the state board may approve the use of disinfected tertiary treated recycled water for these purposes."*

AB 2071 directed the Panel to consider the following resources in conducting its evaluation:

- Recommendations from the existing Advisory Panel on Constituents of Emerging Concerns in Recycled Water;
- State-funded research performed pursuant to Section 79144 and subdivision (b) of Section 79145; and,
- Research by the State Water Board relating to unregulated pollutants.

The Panel's evaluation included due consideration of foregoing and other primary sources, and yielded the following conclusions:

1. Would the use of disinfected tertiary treated recycled water for the purpose of providing water to animals, as defined, pose a significant risk to public health?

   Conclusion: The Panel concluded that there is not sufficient evidence to determine if the use of DTRW for livestock watering would pose a significant risk to public health.

2. Would the use of disinfected tertiary treated recycled water for the purpose of providing water to animals, as defined, pose a significant risk to and animal health?

   Conclusion: The Panel concluded that there is not sufficient evidence to determine if the use of DTRW for livestock watering would pose a significant risk to livestock animal health.

3. If so, what additional uniform recycling criteria (URC) does the Panel recommend?

Given the uncertainties regarding questions 1 and 2, the Panel recommends that DTRW provided to non-dairy livestock should be produced in compliance with the following BMPs:

- Require any DTRW system that provides drinking water to livestock develop and maintain a targeted source control program that complies with the National Pretreatment Program and includes technically based local limits to exclude wastewater inputs from slaughterhouses/abattoirs, zoos, and other significant sources of animal waste, and to exclude concentrated industrial chemicals of concern.
- Require any DTRW system that provides drinking water to livestock to achieve disinfection using an approved ultraviolet (UV) system that meets the disinfection criteria in Title 22 for DTRW. The disinfection must, when combined with the filtration process, be demonstrated to inactivate and/or remove 99.999 percent of the plaque forming units of F-specific bacteriophage MS2, or polio virus in the wastewater. The Panel agreed that UV disinfection is a more effective disinfectant than chlorine for many pathogens of concern.
- Require any DTRW system that provides drinking water to livestock to maintain an appropriate disinfection residual in the DTRW distribution system to prevent microbial growth. The Panel recommends 0.2 mg/L free chlorine or 0.5 mg/L chloramine at the point of use to prevent regrowth of opportunistic pathogens.

The Panel also encourages the State Water Board to coordinate with relevant Federal and State agencies (e.g., USDA, FDA, or CDFA), veterinarians, and others who have a duty to report livestock animal health issues to track the health of animals in herds that receive DTRW through a periodic review and analysis of animal health monitoring data.

6.3 Panel Responses to Questions Posed by the State Water Board

As noted in Chapter 1, early in the Panel process, the State Water Board provided questions to: (1) assist the Panel in addressing the Panel charge, and (2) help the State Water Board meet the requirements of AB 2071. The questions were refined by the Panel and addressed in the following paragraphs. In

developing these responses, the Panel took a conservative approach to prioritize public and animal health and concluded that the anticipated the risk of infection from waterborne pathogens will be negligible compared to other exposure pathways.

Question #1: Is there credible scientific evidence indicating that livestock provided with DTRW as the only water source experience any adverse health effects from either pathogens or chemicals present in the water? If so, what is the strength of the evidence?

Pathogens: There is not sufficient credible scientific evidence to determine whether animals receiving DTRW as the only water source would experience adverse health effects from pathogens in DTRW because little research exists on these topics.

Chemicals: There is not sufficient credible scientific evidence to determine whether adverse health effects from chemicals would result from animals receiving DTRW as the only water source. The Panel did evaluate the limited dose-response data for livestock animals and few published studies that directly investigated the long-term health effects of recycled water on animal models and was unable to reach a conclusion.

Question #2: Is there credible scientific evidence that humans who ingest animal food products (i.e., skeletal muscle, kidney, liver, fat, eggs, and [for poultry] skin with adhering fat) derived from livestock whose only water source is DTRW experience adverse health effects from either pathogens or chemicals present in the water? If so, what is the strength of the evidence?

Pathogens: There is not sufficient credible scientific evidence to determine whether humans who ingest animal food products from livestock whose only water source is DTRW would experience adverse health effects from pathogens in the water. The Panel could not conduct a quantitative risk assessment due to the lack of dose-response data for livestock animals.

Instead, the Panel evaluated the likelihood that DTRW will increase the risk of waterborne disease to livestock based on (1) likely concentrations of human and animal pathogens in DTRW; (2) expectation that these pathogens will be reduced by regulated and well-understood wastewater treatment operations; and (3) implementation of specific additional water recycling criteria recommended by the Panel. The Panel concluded that although people who consume the products of these animals should not experience a quantifiable increase in adverse health effects, the data gaps are significant and additional water treatment is necessary to ensure the safety of DTRW used for livestock watering.

Chemicals: The Panel evaluated the potential health risks to non-dairy livestock that are given DTRW as a sole source of drinking water and the potential health risks to humans from eating animal products from such livestock. In the absence of health-based benchmarks for non-dairy livestock, the Panel took a conservative approach to assessing potential effects on animal health, estimating the concentrations of chemicals in animal products such as meat and eggs, and evaluating potential adverse effects on human health from eating meat and eggs from livestock that are given DTRW.

The Panel determined that chemicals in DTRW are not likely to pose a significant threat to the health of non-dairy livestock given the low concentrations of chemicals in DTRW and the

availability of human health-based benchmarks to evaluate the risk. Furthermore, the Panel found no evidence that meat and eggs from animals that are given DTRW as their sole drinking water source would pose an adverse health risk to people, because of: (1) the conservative nature of estimating the chemical concentrations in meat and eggs; and (2) human health-based benchmarks, such as the acceptable daily intake, using well-established safety factors.

Further, calculations incorporating high thresholds of animal exposures and residue in meat and eggs provided no credible evidence that people would be exposed to concentrations of chemical residues high enough to cause adverse health effects. Finally, the types of meat eaten by most people in the United States and California vary, including beef, pork, poultry, and sheep, in addition to the location that meat is produced. Therefore, the probability of continuous consumer exposure to meat and eggs from animals raised solely on DTRW is extremely low.

However, due to the lack of dose-response data for chemicals of concern in livestock animals, the Panel recommends that the State Water Board should require those who apply for a permit to use DTRW for livestock watering to implement a source control program that complies with the National Pretreatment Program and includes technically based local limits to exclude concentrated industrial chemicals of concern.

Question #3: If there is little to no scientific evidence of an adverse health effect to livestock or humans from watering livestock with DTRW, are there any plausible risks to the health of livestock or humans based upon known pathogens and/or chemicals in water? If a potential adverse effect(s) is identified, how could the effect(s) be identified?

Pathogens: The Panel believes there is a plausible risk that animal pathogens that can affect animal health could be present in DTRW. While these risks are likely to be low, the Panel encourages the State Water Board adopt additional uniform recycling criteria to include the BMPs recommended in this report. It should be emphasized that the Panel used a conservative approach to evaluate both animal and human health risk and concluded that the anticipated the risk of infection from waterborne pathogens will be very low compared to other exposure pathways.

Chemicals: Assuming that WWTPs operate within performance specifications and use appropriate source control, the Panel could not identify plausible risks to livestock or people from chemicals in DTRW. If a potential risk is identified in the future, then the Panel recommends implementing a monitoring program for the specific chemical of concern and/or controls on DTRW to protect livestock and human health.

Although the Panel believes that the BMPs recommendations provided in Chapter 6 would be protective of both animal and human health, they encourage the State Water Board to undertake additional research on these topics when resources are available to do so. The Panel recommends future research efforts to: (1) further characterize concentrations of pathogens of animal health concern in raw wastewater, particularly for sensitive livestock populations, and (2) actively monitor DTRW for specific chemicals to confirm their continued low concentrations.

Question #4: Are the assumed pathogen and chemical risks of adverse health effects for humans applicable to livestock?

Pathogens: Pathogens that cause adverse health effects in people could also affect animals, but the risk is specific to the pathogen and the animal species. The relevance of human pathogens to animal health should be considered on a case-by-case basis. Some pathogens, including genotypes of *Giardia intestinalis*, are capable of infecting both human and animal hosts. Others, such as many viral pathogens, are primarily host-specific and thus less relevant to the transmission of zoonotic disease. To address this issue, the Panel reviewed information on both human and animal pathogens, and notes that for some zoonotic pathogens, variables including infectivity, severity of infection, and resulting illness will differ between human and animal hosts. While some pathogens may cause mild disease in adult livestock populations, these same pathogens may also cause severe sickness in people, or vice versa.

Chemicals: The Panel evaluated risks to livestock and people as described below.

- Risks to livestock. The Panel used regulatory MCLs or other health-based benchmarks for both livestock and human risk assessment to evaluate risks to animal that receive DTRW as a water source. In each case, the concentrations of chemicals in DTRW were projected to be below the animal-based and/or human-based benchmarks. Because measurable toxicity endpoints are sensitive to dose-response relationships, and because benchmarks are calculated using the most sensitive toxicologic endpoints known for each chemical, the Panel assumed that the established benchmarks for people are also fully protective for livestock.
- Risks to people. Humans could theoretically be exposed to risk by ingesting chemical residues in meat or eggs that originated in DTRW consumed by a food animal; however, food animals serve as very efficient filters for most trace-level chemicals present in DTRW. That is, efficient metabolic clearance processes in food animals actively remove most non-nutrient chemicals from the animal's body within hours of exposure. Clearance processes should prevent the accumulation of nearly all waterborne xenobiotics, therefore preventing chemical residues from concentrating in animal tissues. Chemicals with the potential to accumulate in food animals typically are not present in water because they are water insoluble and bind to particles during wastewater treatment. Bioaccumulative compounds such as perfluoroalkyls persist in DTRW in such low quantities that the risk to people consuming meat from animals drinking DTRW would be very low. If, however, source water for DTRW used for livestock watering is contaminated with high concentrations of perfluoroalkyl compounds or other chemicals that may bioaccumulate in livestock animals, then that source water should be excluded through source control measures to eliminate the contaminated input to the WWTP.

Question #5: Is it possible to assess the relative risk of pathogen or chemical exposure between livestock populations that are provided with DTRW as the only water source versus livestock populations that are provided with other sources of water (e.g., municipal, well, or surface sources)?

For both pathogens and chemicals, current water quality for livestock is quite variable, but empirical evidence indicates that the health of livestock generally is unaffected by such variability.

Pathogens: Although DTRW is well-defined with respect to water quality and is of better quality than many water sources currently available to livestock, the Panel was concerned about the lack of dose-response data for pathogens that may affect livestock animals. Given the current data gaps, the Panel could not conduct a risk assessment to answer this question definitively. However, the Panel did conclude that the relative risk of pathogen exposure from animal excreta, dust, feed, biological vectors, current livestock watering sources from surface and groundwater, and animal handlers is orders of magnitude higher for most waterborne pathogens than is likely from exposure through DTRW.

Furthermore, certain pathogens of concern to people that are present in domestic sewage also are part of the indigenous microbiome of various animals, such as *Campylobacter* spp. in poultry and human-pathogenic *E. coli* in cattle. Other pathogen groups, such as the human enteric viruses, generally are not of concern for animal health except for a few strains (such as genogroup C Hepatitis E virus) that infect swine. With respect to *Giardia*, farm prevalence in production animals varies between 0 and 100 percent, with the highest prevalence found in younger animals. The cumulative incidence on a farm where *Giardia* has been diagnosed is 100 percent in cattle and goats and nearly 100 percent in sheep, thus indicating little to no evidence that the anticipated low concentrations of *Giardia* cysts in DTRW will increase the incidence of this protozoal infection in animals (Tomley and Shirley, 2009).

Chemicals: The quality of current drinking water sources for livestock is quite variable, which makes it difficult to assess relative risk for specific sites. However, water derived from municipal supplies or private drinking water wells is generally of defined and consistent quality, and generalizations across water classes can be made with some degree of certainty. For instance:

- Surface water quality will vary across regions, seasons of the year, and drought status. Further, surface waters are major sources of drinking water for wildlife and some food animal species regardless of location, season, and drought status. Empirical evidence indicates that, in general, wildlife and livestock are unaffected when surface waters of widely differing quality are used as water sources. Typically, the chemical quality of surface water is defined in terms of crude quality measures, such as TDS, alkalinity, salinity, turbidity, biochemical oxygen demand, and/or chemical measures such as nitrate, sulfate, and mineral/metal (iron, boron, etc.) content. Some surface waters, however, are not fit for use as wildlife or livestock drinking water sources.
- Groundwater sources generally are of higher quality than surface waters, although groundwaters used for livestock watering can be variably contaminated with many chemicals (ter Laak, et al., 2012; Hildenbrand et al., 2015). Typically, poor groundwater quality is defined as such because of hardness or trace element content. On occasion,

groundwater may not be fit for livestock or wildlife because of excessive content of minerals containing boron, chromium, arsenic, or selenium.

- DTRW is well-defined with respect to water quality endpoints and is of better quality than of many surface water sources used by wildlife and livestock. The organic composition (i.e., TOC, dissolved organic carbon, biodegradable dissolved organic carbon [BDOC]) of DTRWs can vary between sources, but is more consistent, better controlled, and more defined than the organic composition of many surface water drinking sources; therefore, DTRW often is of better quality than either surface water or groundwater sources currently used by wildlife and livestock for drinking water and, in general, is of lesser risk. Because groundwater drinking sources and DTRW both are considered good quality waters for livestock, it is difficult to generalize about the relative risks of DTRW and groundwater sources; however, the Panel concluded that the risks associated with DTRW are no greater than those from most alternative water sources.

Question #6: If adverse health risks are not identified, what monitoring programs (if any) would be recommended to identify potential new or emerging risks?

Pathogens: The Panel identified potential new or emerging risks and therefore made recommendations for future BMPs, including monitoring. The Panel recommends that the State Water Board rely on existing procedures for monitoring pathogens in livestock herds. The Panel also recommends future research when resources are available to characterize concentrations of animal-relevant pathogens in wastewater.

Chemicals: The Panel noted that water treatment facilities are required to monitor treated wastewater, as mandated by the EPA and State of California. Also, the Panel would like to reference the recommendations of the 2012 Science Advisory Panel (SAP) on monitoring approaches for CECs in recycled water. Although the SAP did not focus on using DTRW for livestock, its recommendations are still relevant to the emerging risks to animal or human health, and the Panel recommends that the State Water Board consider the SAP's recommendations when developing future monitoring protocols related to the use of DTRW for livestock watering.

The Panel also recommends that the State Water Board coordinate with relevant Federal and State agencies (e.g., USDA, FDA, or CDFA) to track the health of animals in herds that receive DTRW through a periodic review and analysis of animal health monitoring data and establish a process for notifying these agencies of facilities that use DTRW for livestock watering.

Question #7: If livestock or human health risks are identified or are plausible, are mitigation mechanisms possible to minimize and/or eliminate the risks (e.g., additional treatment steps or recommended withdrawal times for livestock)?

The Panel agreed that livestock or human health risks from using DTRW are plausible given the lack of dose-response data for pathogens and chemicals of concern for livestock health and human health, and the lack of studies on pathogen and chemical exposure for the specific livestock species noted in the

legislation. Therefore, the Panel recommends the following BMPs to ensure that DTRW used for watering non-dairy livestock is protective of human health and animal health:

1. Require applicants to develop and maintain targeted source control that complies with the National Pretreatment Program and includes technically based local limits to exclude wastes from slaughterhouses/abattoirs, zoos, and other significant contributions of animal pathogens and concentrated industrial chemical contaminants.

2. Require any DTRW system that provides drinking water to livestock to achieve disinfection using an approved ultraviolet (UV) system that meets the disinfection criteria in Title 22 for DTRW. The disinfection must, when combined with the filtration process, be demonstrated to inactivate and/or remove 99.999 percent of the plaque forming units of F-specific bacteriophage MS2, or polio virus in the wastewater. The Panel agreed that UV disinfection is a more effective disinfectant than chlorine for many pathogens of concern.

3. Require any DTRW system that provides drinking water to livestock to maintain an appropriate disinfection residual in the DTRW distribution system to prevent microbial growth of opportunistic pathogens. The Panel recommends 0.2 mg/L free chlorine or 0.5 mg/L chloramine at the point of use.

The Panel also encourages the State Water Board to coordinate with relevant Federal and State agencies (e.g., USDA, FDA, or CDFA), veterinarians, and others who have a duty to report livestock animal health issues to track the health of animals in herds that receive DTRW through a periodic review and analysis of animal health monitoring data.

6.4 Recommendations for Future Research

The Panel believes that DTRW produced and delivered according to the BMPs recommended in this document can be used safely for non-dairy livestock watering and recommends that the State Water Board develop uniform water recycling criteria based on the BMPs.

Simultaneous with adoption of the uniform water recycling criteria, the Panel recommends the State Water Board consider commissioning the following research when resources are available to do so:

- Evaluation of updated data on raw water concentrations and the pathogen reductions previously reported by Rose et al. (2004). The data are currently being developed.
- Characterization of concentrations of pathogens of animal health concern. Such pathogens include mycobacteria, *Clostridium* spp., antimicrobial-resistant (AMR) microorganisms, reoviruses, microsporidia, prions, and other known or emerging pathogens of concern in raw wastewater. Such research could clarify the health significance of these pathogens, particularly for sensitive livestock populations.
- A controlled study in which DTRW is provided as the sole water source for a livestock herd (i.e., beef cattle, goats, sheep, broiler chickens, or laying hens) for an extended period to assess the effects on livestock health and to measure concentrations of selected CECs or other chemicals in edible tissues. Tissue analysis should include CECs that are more environmentally stable and may bioaccumulate.

- Assessment of whether a tiered chemical surveillance approach similar to that employed by the USDA Food Safety Inspection Service should be developed.
- Investigation of new performance measures, such as biodegradable dissolved organic carbon (BDOC) and the incorporation of validated bioanalytical screening techniques that could improve current monitoring programs.

6.5 References

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A P P E N D I C E S

APPENDIX 1A: ASSEMBLY BILL 2071 AND THE CALIFORNIA WATER CODE

California Assembly Bill No. 2071, CHAPTER 731

An act to add Section 13521.1 to the Water Code, relating to recycled water.

[Approved by Governor September 28, 2014. Filed with Secretary of State September 28, 2014.]

AB 2071, Levine. Recycled water: animals.

Existing law requires the State Water Resources Control Board to establish uniform statewide recycling criteria for each varying type of use of recycled water where the use involves the protection of public health.

This bill would require, by December 31, 2016, the state board, in consultation with impacted state agencies, to determine whether the use of disinfected tertiary treated recycled water for the purpose of providing water to animals, as defined, would not pose a significant risk to public and animal health. This bill would require the state board to establish uniform statewide recycling criteria for the use of recycled water for the purpose of providing water to animals if the state board determines that the use of disinfected tertiary treated recycled water for this purpose would pose a significant risk to public or animal health. The bill would authorize the state board to approve the use of disinfected tertiary treated recycled water for this purpose if the state board determines that its use would not pose a significant risk to public or animal health but would prohibit the use of disinfected tertiary treated recycled water in the water supply for dairy animals that are currently producing dairy products for human consumption.

The people of the State of California do enact as follows:

SECTION 1. Section 13521.1 is added to the Water Code, to read:

13521.1.

(a) By December 31, 2016, the state board, in consultation with impacted state agencies, shall determine whether the use of disinfected tertiary treated recycled water, as defined by Section 60301.230 of Title 22 of the California Code of Regulations, for the purpose of providing water to animals, would not pose a significant risk to public and animal health. If the state board determines that the use of disinfected tertiary treated recycled water for the purpose of providing water to animals would pose a significant risk to public or animal health, the state board shall establish uniform statewide recycling criteria for the use of disinfected tertiary treated recycled water for the purpose of providing water to animals. Except as provided in subdivision (c), if the state board determines that the use of disinfected tertiary treated recycled water for the purpose of providing water to animals would not pose a significant risk to public or animal health, the state board may approve the use of disinfected tertiary treated recycled water for these purposes.

(b) In evaluating the use of disinfected tertiary treated recycled water for the purpose of providing water to animals, the state board shall consider, at minimum, all of the following:

1. Recommendations from the existing Advisory Panel on Chemicals of Emerging Concerns in Recycled Water.
2. State-funded research performed pursuant to Section 79144 and subdivision (b) of Section 79145.
3. Research by the state board relating to unregulated pollutants.

(c) Disinfected tertiary treated recycled water shall not be used in the water supply for dairy animals that are currently producing dairy products for human consumption.

(d) A person shall not be required to use disinfected tertiary treated recycled water for the purposes described in this section.

(e) The adoption of uniform statewide recycling criteria pursuant to this section shall be subject to the provisions of Chapter 3.5 (commencing with Section 11340) of Part 1 of Division 3 of Title 2 of the Government Code.

(f) For purposes of this section, “animal” includes any domesticated bird, bovine animal, horse, mule, burro, sheep, goat, or swine.

APPENDIX 1B: THE NWRI PANEL PROGRAM

About the National Water Research Institute

Since 1991, the National Water Research Institute (NWRI), a Joint Powers Authority and 501c3 nonprofit located in Fountain Valley, California, has sponsored projects and programs to improve water quality, protect public health and the environment, and create safe, new sources of water. NWRI specializes in working with researchers across the country, such as laboratories at universities and water agencies.

Through its research program, NWRI supports multi-disciplinary research projects related to water treatment and monitoring, water quality assessment, knowledge management, and exploratory research. Altogether, NWRI's research program has produced more than 300 publications and conference presentations.

NWRI also promotes better science and technology through extensive outreach and educational activities, which includes facilitating workshops and conferences and publishing white papers, guidance manuals, and other information.

More information on NWRI can be found online at www.nwri-usa.org.

About the Panel Program

NWRI also specializes in facilitating Independent Advisory Panels on behalf of water and wastewater utilities, as well as local, county, and state government agencies, to provide credible, objective review of scientific studies and projects in the water industry. NWRI panels consist of academics, industry professionals, government representatives, and independent consultants who are experts in their fields.

The NWRI Panel process provides numerous benefits, including:

- Third-party review and evaluation.
- Scientific and technical advice by leading experts.
- Assistance with challenging scientific questions and regulatory requirements.
- Validation of proposed project objectives.
- Increased credibility with stakeholders and the public.
- Support of sound public-policy decisions.

NWRI has extensive experience in developing, coordinating, facilitating, and managing these expert panels, including:

- Selecting individuals with the appropriate expertise, background, credibility, and level of commitment to serve as panel members.
- Facilitating hands-on panel meetings held at the project's site or location.
- Writing report(s) that are prepared by the panel and that focus on findings and comments from various technical, scientific, and public health aspects of the project or study.

During the past five years, NWRI has coordinated the efforts of more than 20 panels for water and wastewater utilities, city and state agencies, and consulting firms. Many of these panels have dealt with projects or policies that involve groundwater replenishment and direct or indirect potable reuse. Specifically, these panels have provided peer review on a wide range of scientific and technical areas related to water quality and monitoring, chemicals of emerging concern, treatment technologies and operations, public health, hydrogeology, water reuse criteria and regulatory requirements, and outreach.

More information about the NWRI Independent Advisory Panel program can be found on the NWRI website at http://nwri-usa.org/Panels.htm.

APPENDIX 1C: ORIGINAL 12 QUESTIONS FROM THE STATE WATER BOARD

Questions for the Panel to Address

The California State Water Resources Control Board (State Water Board) Division of Drinking Water (DDW) Recycled Water Unit provided the following questions to help the Panel focus their investigation and discussions. Answers to these questions are important to help DDW meet the requirements of the California State Assembly Bill (AB) 2071.

1. Does animal consumption of disinfected tertiary recycled water (DTRW), as presently regulated, pose a health risk to animals or humans that consume the animal products?
2. Is there any scientific evidence indicating that animals provided with DTRW have experienced adverse health effects from chemicals (including CECs) or pathogens? How would these affects be noticed?
3. Is there any scientific evidence indicating that humans experience adverse health effects from consuming animal products derived from animals consuming DTRW? Is this different from consuming animal products not derived from animals consuming DTRW?
4. Is the Title 22 assumed risk of 10-4 annual risk of infection acceptable for all animals? Is it acceptable for animals specifically used for human consumption? Is there a need to differentiate between animals used for human consumption and those that are not?
5. Are both pathogens and chemicals a concern, or are only pathogens of concern? Are the risks for animals consuming tertiary recycled water the same as for those that do not? Are the risks from the same pathogens or different pathogens?
6. If chemicals are a concern, what are the health risks to the animals due to chemicals, what are the health risks to humans consuming animal products, and what are the levels and types of chemicals that are of concern?
7. Are Chemicals of Emerging Concern (CECs), particularly endocrine disruptors, a concern to breeding animals such that the CECs may affect their reproduction and development?
8. Do animal products (e.g., meat, eggs, edible-organs) accumulate pathogens or chemicals from tertiary recycled water? To what levels? Is there biomagnification?
9. Are animals susceptible to the same pathogens as humans? Are these pathogens found in DTRW at levels of concern for animals? Are the DTRW treatment criteria effective in controlling the pathogens of concern for animals?
10. Are there different concerns for human exposure when eggs are from chickens raised in a backyard versus those from chickens in an egg production facility?

11. Are animals in a concentrated-animal-facility-operation more susceptible to risks from DTRW than other animals? Are "stressed" animals in such facilities at greater risk of infection?
12. Comment if the Panel feels the risks are similar between the animals listed in AB-2071 and the following animals:
    - Pets (birds, dogs, cats, tropical fish).
    - Exotic zoo animals.
    - Fish raised in hatcheries for food.

APPENDIX 1D: REVISED QUESTIONS FROM THE STATE WATER BOARD

This Appendix includes a table that lists the original 12 questions asked by the State Water Board and subsequent revisions that the Panel made to the questions. In the end, the Panel addressed seven questions.

Table 1D-1: Original Questions Posed by the State Water Resources Control Board and Revisions Made by the Panel

Original Question from the State Water Board (#Q1-12)	Panel's Revised Questions (#RQ1-7)	Working Group Refinements and Comments
Q1. Does animal consumption of disinfected tertiary recycled water (DTRW), as presently regulated, pose a health risk to animals or humans that consume the animal products?	**RQ1**. Is there credible scientific evidence indicating that livestock provided with DTRW as the only water source experience any adverse health effects from either pathogens or chemicals present in the water? If so, what is the strength of the evidence? **NOTE FROM DDW:** Can the Panel define specific adverse health effects that may be caused by pathogens and chemicals found in wastewater? For example, if infection with a microbe causes a certain organ to fail.	**Overall Panel Comment:** Determine how to define animal health for the purposes of this study, including (a) consideration of acute effects and (b) herd health versus an individual animal's health (that is, one animal infected with a highly infectious organism can cause a herd-wide infection). **Pathogen Working Group Questions in May 5 Slides** a) *What do we know about?* What pathogens are of interest for animal (and human) health? b) *What do we care about?* What is known about pathogen concentrations in raw wastewater? c) *Does it get removed?* What level of pathogen removal/inactivation occurs through T22 treatment? d) *How much is left?* What is known about pathogen concentrations in treated wastewater? e) How much additional treatment (or other strategies) would be needed to make risk insignificant? f) *What's a "big deal" for animals?* What constitutes a *significant* risk to animal health? g) Do the concentrations of pathogens present after T22 treatment represent a significant risk? If so, what more (additional treatment, other strategies) can we do? **Chemical Working Group Questions in May 5 Slides** • WG-Q1. Is there scientific evidence that livestock provided DTRW as the only water source experience adverse health effects from chemicals in the water?

Original Question from the State Water Board (#Q1-12)	Panel's Revised Questions (#RQ1-7)	Working Group Refinements and Comments
	RQ2. Is there credible scientific evidence that humans who ingest animal products (i.e., skeletal muscle, kidney, liver, fat, eggs, and [for poultry] skin with adhering fat) derived from livestock whose only water source is DTRW experience adverse health effects from either pathogens or chemicals present in the water? If so, what is the strength of the evidence?	**Pathogen Working Group Questions in May 5 Slides** h) *What's a "big deal" for humans?* What are the pathogen risks to human health through ingestion of animal products? i) Will these risks be significantly higher with ingestion of animals fed DTRW? **Chemical Working Group Questions in May 5 Slides** • WG-Q3. Is there credible scientific evidence that humans who ingest animal products derived from livestock whose only water source is DTRW experience adverse health effects from chemicals in the water?
Q2. Is there any scientific evidence indicating that animals provided with DTRW have experienced adverse health effects from chemicals (including CECs) or pathogens? How would these effects be noticed?	**RQ1** addresses this question.	
	RQ5. Is it possible to assess the relative risk of pathogen or chemical exposure between livestock populations that are provided with DTRW as the only water source versus livestock populations that are provided with other sources of water (e.g., municipal, well, or surface sources)?	**Chemical Working Group Questions in May 5 Slides** WG-Q6. Is it possible to assess the relative risk of chemical exposure between livestock populations that are provided with DTRW as the only water source versus livestock populations that are provided with other sources of water (e.g., municipal, well, or surface sources)?
Q3. Is there scientific evidence that humans experience adverse health effects from consuming animal products derived from animals consuming DTRW? Is this different from consuming animal products not derived from animals consuming DTRW?	**RQ2** addresses this question.	

Original Question from the State Water Board (#Q1-12)	Panel's Revised Questions (#RQ1-7)	Working Group Refinements and Comments
Q4. Is the Title 22 assumed risk of 10^{-4} annual risk of infection acceptable for all animals? Is it acceptable for animals specifically used for human consumption? Is there a need to differentiate between animals used for human consumption and those that are not?	**RQ2** addresses points this question	
Q5. Are both pathogens and chemicals a concern, or are only pathogens of concern? Are the risks for animals consuming DTRW the same as for those that do not? Are the risks from the same pathogens or different pathogens?	**RQ1** addresses this question	
	RQ4. Are the assumed pathogen and chemical risks of adverse health effects for humans applicable to livestock?	**Pathogen Work Group General Comments:** Determine if animal excreta should be tested for selected pathogens. The purpose of this evaluation would be to identify pathogens different from those normally monitored in human drinking water supplies. **Chemical Working Group Questions in May 5 Slides** WG-Q5. Are the assumed chemical risks of adverse health effects for humans applicable to livestock?
Q6. If chemicals are a concern, what are the health risks to the animals due to chemicals, what are the health risks to humans consuming animal products, and what are the levels and types of chemicals that are of concern?	**RQ2** addresses this question	
	RQ5 addresses this question	
Q7. Are Chemicals of Emerging Concern (CECs), particularly endocrine disruptors, a concern to breeding animals such that the CECs may affect their reproduction and development?	Not explicitly addressed in the Panel's revised questions	

Original Question from the State Water Board (#Q1-12)	Panel's Revised Questions (#RQ1-7)	Working Group Refinements and Comments
Q8. Do animal products (e.g., meat, eggs, edible organs) accumulate pathogens or chemicals from DTRW? To what levels? Is there biomagnification?	Not explicitly addressed in the Panel's revised questions. **NOTE FROM DDW:** Please comment on the rate at which pathogens or chemicals accumulate in the animal.	**Chemical Working Group Questions in May 5 Slides** • WG-Q9. How should the Panel approach detections of chemical residues in animal products for which there is no tolerance? **Chemical Work Group General Comments:** • The Panel provided an example calculation to determine potential dose levels of chemical residues in animal products consumed by humans and recommended undertaking additional calculations for relevant chemicals using a worst-case scenario.
Q9. Are animals susceptible to the same pathogens as humans? Are these pathogens found in DTRW at levels of concern for animals? Are the DTRW treatment criteria effective in controlling the pathogens of concern for animals?	**RQ4** addresses this question **RQ7**. If livestock or human health risks are identified or are plausible, are mitigation mechanisms possible to minimize and/or eliminate the risks?	**Chemical Working Group Questions in May 5 Slides** • WG-Q2. Should treatment plants providing DTRW to livestock implement source control for chemicals? • WG-Q8. If livestock or human health risks due to chemicals in DTRW are identified, what mitigation mechanisms are available to minimize and/or eliminate the risks? **Pathogen Work Group General Comments:** • With source control, consider excluding other sources of animal pathogens from wastewater targeted as a source for reuse, such as slaughterhouses, zoos, and animal research laboratories.
Q10. Are there different concerns for human exposure when eggs are from chickens raised in a backyard versus those from chickens in an egg production facility?	The Panel has removed this question from the list of revised questions because it is beyond the scope of the Panel's investigation.	
Q11. Are animals in a concentrated-animal-facility-operation more susceptible to risks from DTRW than other animals? Are "stressed" animals in such facilities at greater risk of infection?	The Panel has removed this question from the list of revised questions because it is beyond the scope of the Panel's investigation.	

Original Question from the State Water Board (#Q1-12)	Panel's Revised Questions (#RQ1-7)	Working Group Refinements and Comments
Q12. Comment if the Panel feels the risks are similar between the animals listed in AB-2071 and the following animals: • Pets (birds, dogs, cats, tropical fish). • Exotic zoo animals. • Fish raised in hatcheries for food.	The Panel has removed this question from the list of revised questions because it is beyond the scope of the Panel's investigation. **NOTE FROM DDW:** DDW agrees this question is beyond the scope of this study, but any information or comments regarding this issue would be very helpful for future regulation interpretations.	
Not addressed in DDW's original questions	**RQ3.** If there is little to no scientific evidence of an adverse health effect to livestock or humans from watering livestock with DTRW, are there plausible risks to the health of livestock or humans based upon known pathogens and/or chemicals in water? If a potential adverse effect(s) is identified, how could the effect(s) be identified? **NOTE FROM DDW:** This is a great addition.	**Chemical Working Group Questions in May 5 Slides** • WG-Q4. Are there theoretical risks to the health of livestock or humans (including appropriate subpopulations, such as animal species, age, or reproductive status) based upon known chemicals in DTRW? **Pathogen Work Group General Comments:** • The Panel agrees that it is important to have benchmarks to determine what type of risk to target. The question is whether benchmarks can be found for animal pathogens. Another area to consider is animal disease mortality. Also, data for secondary infection/spread should be available for key pathogens; however, Title 22 regulations for drinking water do not take into account secondary spread.
	RQ6. If adverse health risks are not identified, what monitoring programs (if any) would be recommended to identify potential new or emerging risks? **NOTE FROM DDW:** This is a great addition.	**Chemical Working Group Questions in May 5 Slides** • WG-Q7. If no adverse health risks can be attributed to chemicals in recycled water, what monitoring programs are recommended to identify emerging risks? **Pathogen Work Group General Comments:** • Consider conducting a comparative study to evaluate pathogens in water both before and after it has undergone treatment. Under this study, if appropriate, develop a list of specific pathogens to monitor in water.

Table 1D-2: Additional Pathogen Working Group Investigations

Not Specifically Related to the State Water Resource Control Board's Original Questions or the Panel's Revised Questions

Item No.	Topic Area	Activity of the Pathogen Working Group
1	Fecal Testing	Determine if animal excreta should be tested for selected pathogens. The purpose of this evaluation would be to identify pathogens different from those normally monitored in human drinking water supplies.
2	Supplemental Needs	Consider the following: • Is there a need for alternate (contingency) water sources? • Is there a need for additional treatment?
3	Pathogen Diversity	Determine the diversity of pathogens extant in untreated water sources (i.e., ditches, stock ponds, etc.) relative to DTRW.
4	Disease	Predict the occurrence and persistence of diseases. Are they treatable?
5	Antibiotic Resistance	Consider the presence of antibiotic resistance and antibiotic resistant genes. Specifically: • Reference efforts at a number of other agencies regarding antibiotic resistant genes. • Compile a list of antibiotics used by animals at food production facilities and compare that list to those antibiotics used by people. • Consider selecting organisms to act as useful monitoring agents for antibiotic resistance. • Address two categories of antibiotic resistant organisms in the Final Panel Report: antibiotic-resistant genes and determinants. • Address organisms that take in antibiotic resistance genes and grow in the distribution system and those that die off.

APPENDIX 3A: CALCULATING WITHDRAWAL PERIODS BY THE FDA CVM

As stated in **Chapter 3**, the purpose of this appendix is to provide supplementary information about the regulation of chemical residues in the tissues of food animals. In particular, this appendix incudes details on the FDA CVM's calculation of a withdrawal period, which is defined as the minimal time required between the last drug exposure and slaughter to ensure that marker residues fall below tolerance levels. This information is taken from pages 26 through 29, Section I, of FDA CVM, 2016. The calculation is included because it provides context for the conservative regulatory governance of chemical residues, whether they are from animal drugs or environmental contaminants.

The depletion of new animal drug residues in an animal is assumed to follow exponential elimination kinetics. This means that the concentration of residues as a function of time after stopping treatment of a drug can be described as the sum of one or more exponential terms (Equation 1).

$$C_t = \sum_{i=1}^{n} C_{0,i}\ e^{-\lambda i t}$$

where:

C_t is the concentration at time t.

$C_{0,i}$ is the extrapolated concentration at time=0 and the ith exponential term.

λ_i is the rate constant corresponding to the ith exponential term.

CVM makes a simplifying assumption for analysis of residue data that the depletion curve, during the phase of the depletion closest to the established tolerance, can be represented by a single exponential equation. This assumption enables the use of ordinary least squares (OLS) regression methods to estimate the intercept (b_0) and slope (b_1) of log-linear depletion curves in either groups or individual animals (Equation 2). The intercept and slope of the line are used to estimate the time at which the concentration in tissue or milk achieves the target tolerance concentration. The straight-line fit of concentration data relies on natural logarithm transformation of the dependent variable (Equation 2).

$$\ln(y)_i = \ln(b_0) - b_1 x_i$$

where:

$\ln(y)_i$ = is the natural log of the regression-estimated concentration at xi.

x_i = the ith sampling period (in units of time) for either tissue or milk samples.

b_0 = regression-estimated intercept of the elimination curve.

b_1 = the estimate of the slope (regression coefficient) from the OLS regression.

Several measures of statistical confidence are used to describe the possible range of values given the variability among the observations. These confidence *limits* include the confidence limits on the regression line and the confidence limits for a new estimate of concentration (taken as ln($\hat{y}$)) given a new value of *x* (also known as "prediction limits"), and the tolerance limits for the new estimates of concentration. The tolerance limits describe an interval in which a specified proportion (*P*) of the sampled population is expected to fall given the current observations (DeGryze et al., 2007). If the true regression parameters for the intercept and slope (β_0, β_1) are known, then the tolerance limits and confidence limits on the new estimate of concentration are the same. Because the true regression parameters are seldom known and must be estimated from the observations, the tolerance and prediction (confidence) limits differ. Tolerance intervals may be either two-sided (for which the estimated parameter is expected to lie between a lower and upper limiting value) or one-sided, (in which the estimated parameter is expected to lie above or below a specified limit). CVM uses a one-sided tolerance limit to set an upper limit on the concentration of residue in tissue or milk.

CVM uses a 99th percentile tolerance with 95-percent confidence as an upper limit of residue concentration in either tissue or milk. In general terms, this means that a new individual value of concentration, randomly sampled from animals at the proposed withdrawal or discard period, is expected to have only a 1% chance of exceeding the established tolerance limit. The purpose of the regression error (variance) analysis is to calculate uncertainty (e.g., $y \pm s$) in the estimated concentration near the proposed tissue withdrawal period or milk discard time. CVM solves for a factor, *k*, that adjusts the regression-estimated error (*s*) for the 99th percentile tolerance with 95-percent confidence. In the form of a linear equation (y = b + mx) the residue calculation to estimate *y* from a new value of $\boldsymbol{x}_0$ (Equation 3):

$$\ln(y) \mid x_0 = (\ln(b_0) - b_1 x_0) + k$$

The modifying factor, *k*, is derived from the noncentral *t*-distribution, and it is a function of degrees of freedom, the distance from the expected value of ln(y), the desired proportion of coverage for future values (*P*=0.99) and the confidence level for the difference ($1 - \alpha = 0.95$). The noncentral *t*-distribution can be obtained from tables of the noncentral *t*-distribution (Owen 1968) or statistical software.

CVM solves Equation 3 for the value of $x = T$, the tissue withdrawal period or milk discard time. Given simultaneous unknown values in Equation 3, the value of *x,* such that concentration estimated at $x = T$ satisfies the 99/95 tolerance condition*,* is found iteratively either by hand or computer program. The general location of the tolerance limit, the withdrawal period or discard time (*T*) and the various OLS regression results are shown in **Figure 3A-1.**

Calculation of the tolerance from the linear regression data relies on first calculating the amount of variation among the observations (samples). The sources of variation include both the within-animal variation as a function of the sampling time, and variation from the difference among the animals. Laboratory analytical variability also contributes to overall variability. The assumptions for OLS regression include that the samples are independent from each other; the residue assays are independent from each other and from the animal in question; the depletion of the concentration of residue is log linear with time; and the measured log(concentration)s of residue are distributed normally and have a constant variation over the time periods. The validity of the assumptions for an experiment

can be examined using analysis of variance for regression and various diagnostic statistics (Draper and Smith 1998). Generally, statistical software or spreadsheets with statistical functions can be used to calculate the intercept, slope, and regression diagnostics.

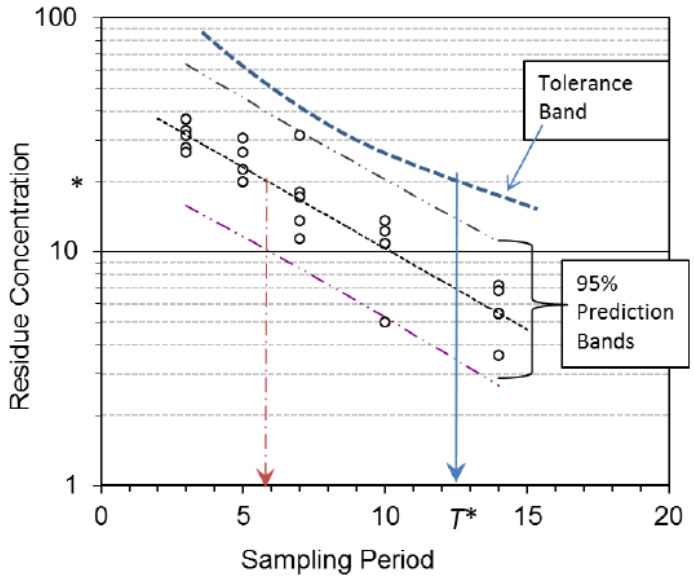

Figure 3A-1. Hypothetical residue depletion curve and withdrawal period estimate. A least square fit of the data (circles) is shown as a decreasing, straight and small-dashed line through the data. The 95-percent prediction bands and the 99th percentile tolerance for the upper 95-percent confidence limit are shown. If the regulatory limit is the value of concentration marked by the asterix (*=2 units), then the regression analysis predicts that the withdrawal period (*T**) is about 12.5 sampling period units determined by where the tolerance band crosses the desired limit. Note that the tolerance band is not drawn to scale for ease of presentation: the tolerance generally lies much closer to the upper 95% prediction band.

References

DeGryze, Langhans, and Vandebroek (2007). Using the correct intervals for prediction: a tutorial on tolerance intervals of ordinary least-squares regression. *Chemometrics and Intelligent Laboratory Systems, 87*(2):147–154, 2007.

Draper, N.R. and Smith, H (1998). Applied Regression Analysis. 3th Edition, Wiley, NY.

FDA CVM (2016). Guidance for Industry: General Principles for Evaluating the Human Food Safety of New Animal Drugs Used In Food-Producing Animals. Center for Veterinary Medicine, Food and Drug Administration, Rockville, MD.

APPENDIX 3B: WATER QUALITY STANDARDS FOR CHEMICALS, ANDERSON ET AL. (2010)

The text below is reproduced from Appendix J of Anderson et al. (2010), a report prepared for the California State Water Resources Control Board to provide expert guidance on developing monitoring programs that assess potential threats of constituents of emerging concern from various water recycling practices, including: indirect potable reuse via surface spreading; indirect potable reuse via subsurface injection into a drinking water aquifer; and urban landscape irrigation.

California Department of Public Health (2007). Drinking Water Notification Levels and Response Levels: An Overview. Drinking Water Program.

- Notification levels are calculated using standard risk assessment methods for non-cancer and cancer endpoints, and typical exposure assumptions, including a 2-liter (L) per day Drinking Water Consumption (DWC) rate, a 70-kilogram (kg) adult body weight (BW), a 70-year lifetime, a Relative Source Contribution (RSC) of 0.2, a 10^{-6} cancer risk, and the upper 95-percent confidence limit on the cancer Slope Factor in $(mg/kg\text{-}day)^{-1}$ (q_1*).
- Non-carcinogens: C = (NOAEL x BW x RSC)/(MF x UF x DWC).
- Carcinogens: C = (BW x 10^{-6})/(q_1* x DWC).

EPA CCL 3 List/PCCL

- For the CCL process, health reference levels (HRLs) were calculated by converting the RfD or other dose to µg/L, assuming 2 L/day of water consumed by a 70-kg adult, and a RSC of 20 percent.
- For carcinogens, the concentration at the 10^{-6} cancer risk was used and no RSC was included, assuming a 70-year exposure.

Schwab et al. (2005). Human pharmaceuticals in US surface waters: a human health risk assessment. *Regulatory Toxicology and Pharmacology* 42: 296-312.

Note that values provided in the summary table with benchmarks from all the studies are for child receptors (which are more conservative than adults), with exposure parameters as follows:

$$PNEC_{DW} = \frac{1000 \times ADI \times BW \times AT}{IngR_{DW} \times EF \times ED}$$

- Body weight: 14 kg.
- Water consumption: 1 L/day.
- Exposure frequency: 350 days/year.
- ADI averaging time: 2,190 days.

Environment Protection and Heritage Council et al. (2008). Australian Guidelines for Water Recycling. Augmentation of Drinking Water Supplies.

- Assume a bodyweight of 70 kg for adults and 13 kg for a 2-year old child.
- Based on a risk of 10^{-6}.
- 2 L/day for an adult and 1 L/day for a 2-year-old child.
- Proportion (P) from water varies. For human-use pharmaceuticals, use P=1.0. For other CECs, the default is P=0.1.

Drinking Water Guideline (SF = Safety Factor):

$$(mg/L) = \frac{NOEL\ ((mg/kg\ bw)/d) \times bw\ \times P}{SF \times V\ (L/d)}$$

For Carcinogens (SF = slope factor):

$$mg/L = \frac{Risk\ \times P\ \times BW\ (kg)}{SF\ (mg/kg\ day) \times V\ (L/d)}$$

Snyder et al. (2008). Toxicological Relevance of EDCs and Pharmaceuticals in Drinking Water. Water Research Foundation.

- ADIs were converted to DWELs by multiplying the ADI by 70-kg BW and dividing by 2 L/D (average daily ingestion rate of water).
- Carcinogens assumed a cancer risk of 10^{-6}.
- Noncarcinogens:

$$DWEL = \frac{ADI * 70\ kg * 1{,}000{,}000\ ng/mg}{2\ L/day}$$

- Carcinogens (SF = Slope Factor):

$$\frac{10^{-6} * 70\ kg * 25550\ days * 1{,}000{,}000\ ng/mg}{SF * 2\ L/day * 30\ years * 365\ days}$$

Schriks et al. (2009). Toxicological relevance of emerging contaminants for drinking water quality. Water Research.

- A drinking water equivalent level (DWEL) was calculated by multiplying the TDI by a typical average body weight of 70 kg and division by a daily water consumption of 2 L. The DWEL was multiplied by a default allocation of 10 percent.
- Cancer risk to an individual = 10^{-5} over a 70-year lifetime.

Cotruvo et al. (2010). Identifying Health Effect Concerns of the Water Reuse Industry and Prioritizing Research Needs for Nomination of Chemicals for Research to Appropriate National and International Agencies.

- 60 kg = Default adult body weight.
- 0.2 = Default Relative Source Contribution from drinking water of 20 percent.
- L/day = Default daily drinking water intake for a 60-kg adult.

$$Action\ Level = \frac{ADI \times 60\ kg\ \times 0.2}{2\ L/d}$$

References

Anderson, P., Denslow, N., Drewes, J.E., Olivieri, A., Schlenk, D. and S. Snyder (2010). *Final Report: Monitoring Strategies for Chemicals of Emerging Concern (CECs) in Recycled Water. Recommendations of a Science Advisory Panel*. State Water Resources Control Board, Sacramento, CA.

CDPH (2007). *Drinking Water Notification Levels and Response Levels: An Overview*. California Department of Public Health, Drinking Water Program.

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Snyder (2008). *Toxicological Relevance of EDCs and Pharmaceuticals in Drinking Water*, *AwwaRF Project 3085 – WRF 04-003*. Awwa Research Foundation, Denver, CO. 484 pp.

APPENDIX 3C: CANADIAN WATER QUALITY GUIDELINES FOR THE PROTECTION OF AGRICULTURE

As described in **Section 3.3.2** of **Chapter 3**, the Canadian Council of Ministers of the Environment published the *Water Quality Guidelines for the Protection of Agriculture* to establish the safety of chemicals in water used for agricultural irrigation and as livestock drinking water (CCME, 1999). These guidelines are based on tolerable daily intakes (TDI), defined as "an estimate in milligrams per kilogram body weight per day of a substance that is not anticipated to result in any adverse health effects following chronic exposure to a population of livestock species, including sensitive subgroups" (CCME, 1999). Guideline values are derived using the methods shown below.

The TDI ($mg \cdot kg^{-1} \cdot d^{-1}$) is calculated from chronic toxicology studies in which a statistically significant ($P < 0.05$) No Observable Adverse Effect Level (NOAEL) and a Lowest Observed Adverse Effect Level (LOAEL) are derived, the geometric mean is calculated, and the mean then divided by an uncertainty factor (UF):

$$TDI = (LOAEL \cdot NOAEL)^{.5} \div UF$$

For instances in which a NOAEL is unknown, the TDI may calculated as

$$NOAEL = LOAEL \div 5.6$$

based on the 95-percent confidence limit of the ratio of LOAEL:NOAEL across a number of chemicals and farm animal species. The UF is generally set to 10 unless there is sufficient justification to set it higher or lower.

The Canadian guidelines include a provision for calculating a NOAEL when only acute data are extant. In such cases, the TDI is estimated using a mean acute-to-chronic toxicity ratio of 69.2 (rounded up to 70) calculated by the Michigan Department of Natural Resources. The TDI in such cases is calculated as:

$$TDI = (LD_{50} \div 70) \div UF$$

Reference concentration (RC), a relative measure of sensitivity, for each species in which a full toxicology profile exists is then calculated from TDIs:

$$RC = (TDI \cdot BW) \div WIR$$
$$mg \cdot L^{-1} = [(mg \cdot kg^{-1} \cdot d^{-1})kg \div L \cdot d^{-1}$$

Where BW is the animal's body weight and WIR is the water intake rate in $L \cdot d^{-1}$. In instances in which full toxicology portfolios are incomplete, an interim guideline can be calculated using the available TDI divided by the most conservative (i.e., the largest) body weight/water intake across livestock species (see Table 1 of CCME, 1999). At this point, the reference concentration does not reflect the fact that for most environmental contaminants, drinking water contains only a portion of the total daily dose that an animal might encounter. For the Canadian Guidelines, a default value of 20-percent typically is used for

the percentage drinking water contribution (PDWC) except when specific data would suggest otherwise; therefore, the Canadian Drinking Water Guideline for Livestock ($CDWG_L$) is calculated by:

$$CDWG_L = RC \cdot PDWC$$

Reference

Canadian Council of Ministers of the Environment (1999). Water Quality Guidelines for the Protection of Agriculture; Livestock.

APPENDIX 4A: ANTIMICROBIAL RESISTANCE

4A.1 Antimicrobial Resistant Bacteria and Antibiotic Resistant Genes

An emerging issue, antibiotic-resistant bacteria (ARB) and antibiotic-resistant genes (ARG) generally are present both in wastewater and other sources of water not necessarily impacted by wastewater (Olivieri et al., 2016). While the presence, persistence, and proliferation of ARB and ARGs is of critical concern for the protection of animal and human health, it is important to remember that antibiotics and ARGs were first isolated from naturally occurring soil microbes, and that the environment may still be an important pathway for the development of resistance. Examples of ARBs of concern in regard to livestock and human health include:

- **AMR *Salmonella* spp. (especially *S. enterica* serovar Typhimurium)**. *S. enterica* strains show a high proportion of multi-drug resistance, including antimicrobial resistant (AMR) *Salmonella* isolated from wastewater in the United States and various other countries. For example, one isolate of *S. enterica* serovar Typhimurium was resistant to 18 antibiotics (Masarikova et al., 2015). Potential future surveillance and monitoring programs of effluents before and after treatment and discharge into the environment may warrant a better understanding of the survival and proliferation of ARB and ARG through wastewater treatment and comparison to isolates associated with animals watered with DTWR.
- ***Arcobacter butzleri and A. cryaeophilus***. *Arcobacter butzleri* is an emerging human foodborne pathogen and cause of gastroenteritis. Various *Arcobacter* spp. are causes of diarrhea and abortion in livestock, including cattle, sheep, and swine. Poultry meat, such as chicken, duck, and turkey, is considered a plausible source of these pathogens for people, with livestock considered reservoirs. Arcobacters are known to contain antimicrobial resistance, including multi-drug resistance. While there is little information in the literature, there is some evidence that *Arcobacter* spp. are orders of magnitude more numerous than related campylobacters, with viable cells present in treated wastewater, even after UV disinfection (Banting et al., 2016). WWTPs that maintain slaughterhouse effluents in their source waters could be important sources of AMR arcobacters in DTRW and should be evaluated to determine their presence.
- **AMR *Acinetobacter* spp**. *Acinetobacter baumannii* is a cause of mastitis in cattle, and AMR strains are on the WHO high priority list for control (WHO, 2017b). In swine, it is a cause of pneumonia and sepsis. In horses, it has been a cause of sepsis, encephalopathy, wounds, bronchopneumonia, eye infection, uterine infection, and I.V. catheter infection. Multi-drug resistant strains also are reported from sewage (Hrenovic et al., 2016). Other species, such as *Acinetobacter calcoaceticus,* cause mastitis, metritis, and abortion in cattle, and cause septicemia and myositis in horses and septicemia in chickens.
- Other important AMR resistant bacteria that may be present in sewage effluents include AMR *E. coli,* AMR *Pseudomonas* spp., AMR *Aeromonas* spp., AMR *Bacteroides* spp., and AMR *Enterococcus* spp. (Luczkiewicz et al., 2013; et al., Narciso-da-Rocha et al., 2017), as well as AMR

genes within endemic wastewater bacteria (Guo et al., 2017) and receiving waters associated with animal production (Jia et al., 2017).

4A.2 Background and Key Agencies Involved

All bacterial pathogens described in this report have been reported to express antimicrobial resistance through one to many ARGs, a growing problem due to the loss in efficacy in treating human and animal infections. This increasing resistance has led various national and international agencies, such as WHO, European Commission, FAO, and CDC, to take specific actions to combat AMR (EFSAECDC, 2017; EU, 2015; O'Neill, 2016; The White House, 2015; WHO, 2014; WHO, 2017b); however, it also is important to recognize that ARGs often are "packaged" on segments of DNA with mobile genetic elements, such as plasmids and transposons, that may also contain heavy metal resistance and/or virulence genes (Arias and Murray, 2012; Gebhardt et al., 2015; Holt et al., 2015; Zhang et al., 2016; Singh et al., 2017). The co-presence of virulence genes may make resistant bacterial pathogens more or differently infectious than non-resistant strains; hence, available pathogen dose-response models [35] may not be applicable to strains with increased virulence.

The US Centers for Disease Control and Prevention (CDC) recently announced that it will spend more than $200 million to help states respond to infectious disease threats, which included $77 million directly to state health departments to support the CDC's Antibiotic Resistance (AR) Solutions Initiative (CDC, 2017). This investment is meant to enhance the AR Lab Network, which monitors known and emerging AMR threats that are largely associated with clinical settings, such as increased testing nationwide for *Candida* fungal infection, enhanced detection of drug-resistant gonorrhea, and a new national tuberculosis (TB) center that is equipped to sequence whole genome for all TB isolates in the United States. More relevant to this report, however, is the CDC's national laboratory network, known as PulseNet, which connects foodborne illness cases to help identify foodborne outbreaks and includes AMR data (CDC, 2016b).

In collaboration with the CDC, the USDA and FDA compiled the 2014 National Antimicrobial Resistance Monitoring System (NARMS) Integrated Report (published in November 2016).[36] This "One Health" approach to integrated surveillance provides information needed to assess the nature and magnitude of resistance in bacteria moving through the food supply and causing illnesses in people. Key findings reported by the FDA, which focused mostly on *Salmonella* and *Campylobacter*, can be found at NARMS (2017). For example, the first key point included, "Seventy-six percent of *Salmonella* isolated from people had no resistance to any of the 14 antimicrobial drugs tested" (NARMS, 2017).

In California, the presence of antimicrobial resistance in the bacteria of livestock and people is monitored by the CDFA Antimicrobial Use and Stewardship program (AUS), which involves "a

35 http://qmrawiki.canr.msu.edu/index.php/Dose_Response

36 https://www.fda.gov/AnimalVeterinary/SafetyHealth/AntimicrobialResistance/NationalAntimicrobialResistanceMonitoringSystem/ucm059103.htm

coordinated effort by physicians, veterinarians, individual patients, animal caretakers and producers" to "preserve the efficacy of antimicrobial drugs." It provides the education and tools to help make decisions regarding disease prevention and the judicious use of antimicrobials in livestock, with the goal of preventing and mitigating the emergence of new antimicrobial resistant strains of pathogenic bacteria (CDFA-AUS, n.d.). Notably, in 2018, California became the first state in the United States to restrict the use of all forms of antibiotics to therapeutic purposes in livestock.[37]

4A.3 Significance for Antimicrobial Resistance Bacteria in DTRW

As a result of the growing incidence rates in human AMR cases, municipal wastewater is increasingly a source of AMR pathogens and non-pathogens (Bengtsson-Palme et al., 2016). ARBs have been reported in higher proportions in untreated wastewater and wastewater effluents as compared to surface water (Olivieri et al., 2016). Furthermore, biological secondary wastewater treatment may further enhance the transfer and amplification of AMR within wastewater bacteria, as measured by culture and molecular methods (Jury et al., 2011; Yang et al., 2014), in part due to the presence of residual antibiotics (Xu et al., 2015; Lundström et al., 2016), but also because of other determinants for ARG transfer, such as metals, biocides, and disinfection processes (Bengtsson-Palme et al., 2016; Di Cesare et al., 2016; Lin et al., 2016; Hu et al., 2017; Zhang et al., 2017). Nonetheless, physical removal and disinfection processes reduce ARGs and AMR pathogens overall (Al-Jasim et al., 2015; Li et al., 2015; Kassotaki et al., 2016; Li et al., 2017).

Hence, culture-based and molecular (largely PCR-based) methods will detect resistant bacteria (viable and total, respectively, including dead bacteria) in treated wastewater, but few studies report the relative number of resistant viable cells compared to background levels (Pepper, 2017). While there has been concern raised due to the incomplete removal of ARGs (in dead/live cells and pathogens/non-pathogens) during wastewater treatment (Rodriguez-Mozaz et al., 2015), probably only very high concentrations matter from an ecological perspective (i.e., the potential impact to environmental bacterial communities). That is, the relatively low concentration of genes potentially remaining in DTRW makes it very unlikely for ARG uptake to occur, let alone amplify, in the few viable pathogens that may be present. As a corollary of AMR pathogens in excreta, it is probably more important not to add animal wastewaters to sources of DTRW, given the release of known animal pathogens and emerging AMR strains at higher concentrations from animals than in municipal wastewater (Mollenkopf et al., 2017).

In summary, the concentrations of ARGs expected in municipal DTRW, while potentially variable, are likely trivial compared to other environmental direct or indirect exposure routes in animal production facilities (e.g., animal-to-animal, fecal/soil dust-to-animal) (Pepper, 2017). However, there is an urgent need to extend the QMRA concept in a way that captures the environmental dimension of antibiotic resistance (Ashbolt et al., 2013). Progress toward risk assessment is essential to link human [and animal] exposure to antibiotic-resistant bacteria (ARBs) able to cause infection and antibiotic resistance genes (ARGs) present in the environment or excreted by domestic animals or people (Pruden et al., 2018). Efforts to establish potential risk levels, while important for understand treatment targets, have been

37 https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160SB27.

largely unsuccessful to date. In the absence of scientific-based information on risk associated with animal exposure with ARGs, the use of future monitoring programs may be a feasible pathway forward. While the most meaningful monitoring targets are yet to be identified, methods that provide quantitative measures of exposure and health effects will provide the greatest value from a risk characterization and assessment standpoint (Pruden et al. 2018). What is of potential concern (but of very low likelihood) is for a novel AMR pathogen to enter and develop within the post-treatment distribution system for DTRW; however, pathogen entry and propagation also is a low-likelihood risk for potable water distribution systems (Khan et al., 2016). The impact of water distribution systems on water quality was considered outside the scope of this report.

4A.4 Potential Monitoring Targets for Antimicrobial Resistance

Both pathogen and surrogate measures are available to verify change in AMR within DTRW. Of the listed animal bacterial pathogens as potential "index" members for AMR, those that may grow during wastewater treatment and contain important ARGs may provide the most useful targets, such as various pathogenic *Arcobacter* spp. (Al-Jassim et al., 2015; Webb et al., 2016; Ferreira et al., 2017) or more readily using supplemental testing of *E. coli* isolates (Matheu et al., 2017). As seen for other AMR non-pathogenic wastewater bacteria (Narciso-da-Rocha and Manaia, 2017), bacteria that grow during wastewater treatment have the greatest potential for ARGs to amplify. Hence, *Arcobacter butzlier* was listed in **Chapter 4** as a possible addition to *E. coli* AMR monitoring as a reference enteric bacterial pathogen known to proliferate during wastewater treatment and possibly take up more ARGs.

Alternatively, genes involved in the horizontal gene transfer of ARGs (the transfer of ARGs from one bacteria to another), such as class 1 integron integrases, could provide an even more sensitive understanding of conditions for AMR changes though water treatment (Gillings et al., 2008; Li et al., 2015; Farkas et al., 2016; Aubertheau et al., 2017; Ma et al., 2017; Zhao et al., 2017).

Most studies to date, however, have focused on the monitoring of culturable *E. coli* in treated waters followed by screening for specific resistance genes by molecular methods. For example, the WHO has a program targeting extended spectrum beta-lactamase producing *E. coli* (ESBL-*E. coli,* Blaak et al., 2015; Franz et al., 2015; Müller and Nüesch-Inderbinen, 2016), given their clinical and animal significance (Arcilla et al., 2017; ESFA/ECDC, 2017; Willyard, 2017) and ease to assay following conventional culture for water quality monitoring of wastewaters.

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APPENDIX 4B: PATHOGENS OF POTENTIAL CONCERN IN UNTREATED (RAW) WASTEWATER

Pathogens in Untreated Wastewater and Concern for Humans and Livestock

The following tables identify pathogens, such as bacteria, viruses, protozoa, and helminths that potentially may be present in untreated (raw) wastewater. These tables were adapted from EPA (2012), which focused on human health, and were modified by the Panel to account for livestock health or impacts to the livestock industry—including mandatory culling if the presence of these pathogens is detected in a herd or flock. These tables are provided for informational purposes only; please see **Chapter 4** for a complete discussion and conclusions regarding the microbial safety of DTRW as a source of drinking water for commercially produced non-dairy livestock and associated impacts on the health of people in contact with this water or consuming animal-derived products.

For ease of reference, the pathogens listed in **Tables 4-2** and **4-9** in **Chapter 4** (representing pathogens of concern for DTRW) are highlighted in the tables in Appendix 4B in green. Because concentrations of pathogens of concern to animal health are not well characterized in wastewater, the lack of information or data may be represented in the tables as dashes (--).

Sources for these tables include: NRC, 1996; Sagik et al., 1978; Hurst et al., 1989; WHO, 2006; Feachem et al., 1983; Mara and Silva, 1986; Oragui et al., 1987; Yates and Gerba, 1998; da Silva et al., 2007; Haramoto et al., 2007; Geldreich, 1990; Bitton, 1999; Blanch and Jofre, 2004; and EPHC, 2008; Poffé and Beeck, 1991; Bofill-Mas et al., 2006; Rafique and Jiang, 2008; QMRA Wiki, 2015; Kitajima et al., 2018; Symonds et al., 2014; da Silva et al., 2008; Gerba et al., 2018.

Table 4B-1: Infectious Bacteria that Are Potentially Present in Untreated (Raw) Wastewater

Pathogen (Bacteria)	Human Health Disease	Quantity in Raw Wastewater (per liter)	Method of Quantification	Relevance to Livestock
Acinetobacter baumannii, A. calcoaceticus, A skirrowii, A cryaerophilus A thereius	Opportunistic infection: Pneumonia, sepsis, meningitis, urinary tract infection, necrotizing fasciitis (often antimicrobial resistant)	--	--	Mastitis, diarrhea, metritis, and abortion in cattle. Diarrhea and abortion in sheep. Septicemia, myositis, encephalopathy, pneumonia, and uterine infection in horses. Abortion, sepsis, and pneumonia in swine. Septicemia in chickens.
Aeromonas hydrophila	Gastroenteritis, peritonitis, meningitis, cellulitis, pneumonia, bacteremia	Up to 10^3	Culture	*Aeromonas* spp. causes diarrhea in horses.
Arcobacter butzleri A. cryaerophilus	Gastroenteritis	Up to 10^7	Culture+PMA-PCR (Webb et al., 2016; Banting et al., 2016)	Diarrhea and abortion in livestock (i.e., cattle, sheep, pigs). Poultry meat may be a source for people. A comprehensive review of *Arcobacter* as a zoonotic pathogen can be found in Ramees et al. (2017).
Atypical mycobacteria	Respiratory illness (hypersensitivity pneumonitis)	--	--	Infection of cattle and other ruminants causes costly regulatory culling due to false positive on tuberculosis testing. Gastrointestinal disease in swine and respiratory disease in poultry.
Campylobacter spp.	Gastroenteritis, reactive arthritis, Guillain-Barré syndrome	Up to 10^4	Culture	Enteritis in calves, heifers, and young horses. Suggested cause of mastitis in cows. In sheep, it may cause abortions, stillbirths, and weak newborn lambs. Poultry (i.e., chickens, turkeys, ducks, and pigeons) are an important reservoir host for human foodborne infections. It causes diarrhea in 3-day old chicks. In adult poultry, it can be asymptomatic or may cause hepatitis or decreased egg production.

Pathogen (Bacteria)	Human Health Disease	Quantity in Raw Wastewater (per liter)	Method of Quantification	Relevance to Livestock
Clostridium perfringens types A, B, C, D, E	Gastroenteritis, necrotizing enteritis	--	--	Enteritis and hemorrhagic enterotoxemia in cattle, sheep (including yellow lamb disease), goats, pigs, and horses. Dysentery in lambs and diarrhea in calves and foals.
Clostridium difficile	Gastroenteritis	--	--	Enteritis in horses, swine, and calves. Some identical to human strains.
Enteropathogenic *Escherichia coli* (many other types of *E. coli* are not harmful)	Gastroenteritis and septicemia, hemolytic uremic syndrome (HUS)	Up to 10^7	Culture	Ruminants and swine can be a source for human infection.
Helicobacter pylori	Chronic gastritis, ulcers, gastric cancer	--	--	Not known to be important.
Legionella spp.	Respiratory illness (pneumonia, Pontiac fever)	--	--	Not important.
Leptospira spp.	Leptospirosis	--	--	Disease of liver and kidney, causing septicemia, fever, abortions, mastitis, and hemolysis in livestock (i.e., ruminants, horses, and swine).
Mycobacterium spp.	---	---	---	Chronic diarrhea and weight loss in cattle, sheep, and goats. Results in false positive culling due to cross-reaction on tuberculosis tests. Chronic granulomatous bacterial disease and weight loss in poultry. Intestinal infection and granulomas of lymph nodes in swine.
Mycobacterium avium paratuberculosis	Not known: Controversial	Unknown (Can survive chlorine disinfection and propagate when within *Acanthamoeba* spp.)	-	The cause of Johne's disease, a contagious and usually fatal infection that affects primarily ruminants. Involves chronic diarrhea and weight loss in cattle, sheep, and goats. Results in false positive culling due to cross-reaction on tuberculosis tests.

Pathogen (Bacteria)	Human Health Disease	Quantity in Raw Wastewater (per liter)	Method of Quantification	Relevance to Livestock
Mycobacterium tuberculosis (MTB) Complex	Tuberculosis caused by *M. tuberculosis* ("human tuberculosis") and *M. bovis*: scrofula, extrapulmonary TB, pulmonary TB, renal TB, Spinal and meningeal TB, hunchbacks	Unknown	--	Tuberculosis: Emaciation, pulmonary tuberculosis, mastitis, decreased production in ruminants. Gastrointestinal and pulmonary disease in swine. Regulatory culling of individuals ruminants or whole herd due to infection. Source of bovine tuberculosis for people via dairy products or direct exposure.
Pseudomonas aeruginosa	Skin, eye, ear infections	--	--	Problematic infections in livestock, which are difficult to treat.
Salmonella spp.	Salmonellosis, gastroenteritis (diarrhea, vomiting, fever), reactive arthritis, typhoid fever			Diarrhea, fever, abortion, and sepsis in cattle, swine, and horses.
Salmonella enterica	Salmonellosis, gastroenteritis (diarrhea, vomiting, fever), reactive arthritis, typhoid fever	Up to 10^5	Culture	Gastroenteritis, septicemia, abortion, and sometimes death in livestock (horses, ruminants, and swine) caused by many species (but not *S. typhi* or *S. paratyphi*). Some cause enteritis and septicemia in poultry and chick death. Poultry and livestock can be an important source for human infection.
Shigella spp.	Shigellosis (bacillary dysentery)	Up to 10^4	Culture	Not important.
Staphylococcus aureus	Skin, eye, ear infections, septicemia	--	--	Gangrenous mastitis in ruminants and swine, abortions in horses, death for all of the above. Omphalitis and gangrenous dermatitis in poultry.
Vibrio cholerae	Cholera	Up to 10^5	Culture	Reported as a cause of enteric disease in horses, lambs, and bison in 1985, but possibly other agents were involved. Notably, vibriosis in sheep is cause by *Campylobacter*, not *Vibrio*. Common in surface waters and saline waters.

Pathogen (Bacteria)	Human Health Disease	Quantity in Raw Wastewater (per liter)	Method of Quantification	Relevance to Livestock
*Yersinia enterocolitic*a	Yersiniosis, gastroenteritis, and septicemia	--	--	Sometimes causes enterocolitis and diarrhea in young ruminants and swine. Causes regulatory culling due to false serologic cross-reaction with *Brucella* spp. in cattle and swine. Livestock are a source human infection.

Note: The dash "—" represents a lack of data or information as related to animal health.

Table 4B-2: Infectious Helminths that Are Potentially Present in Untreated (Raw) Wastewater

Pathogen (Helminths)[a]	Human Health Disease	Quantity in Raw Wastewater (per liter)	Method of Quantification	Relevance to Livestock
Ascaris	Ascariasis (roundworm infection)	Up to 10^3	Culture/direct count	In swine, decreased growth, gastrointestinal obstruction, liver fibrosis (resulting in condemnation of liver at slaughter), and secondary bacterial lung infection. Possible source for people (also, *Baylisascaris* from raccoon feces cause clinical larval migrans and neurological disease in chickens).
Ancylostoma	Ancylostomiasis, Cutaneous larva migrans (hookworm infection)	Up to 10^3	Culture/ direct count	Not important.
Echinococcus	Hydatidosis (tapeworm infection)	--	--	Hydatidosis: Important cause of hydatid cysts and sometimes neurological disease in ruminants and swine. Causes condemnation at slaughter. Risk would be from dog or coyote feces in sewage.
Enterobius vermicularis	Enterobiasis (pinworm infection)	Up to 10^4	PCR (Rudko et al., 2017)	Not important.
Necator	Necatoriasis (roundworm infection)	--	--	Not important.
Strongyloides	Strongyloidiasis (threadworm infection)	--	--	Not important. *Strongyloides* spp. from livestock gastrointestinal tracts can cause human cutaneous larval migrans, but any lifecycle completion is highly unlikely between these hosts.
Taenia solium	Neurocysticercosis, which is tapeworm cysts in the brain, and ophthalmic cysticercosis of the eye.	---	---	Porcine cysticercosis, which may require condemnation or freezing of pork carcasses found to be affected. Tapeworm eggs in human feces is the source of infection for cattle and swine. Cysticercosis has been associated with feeding cattle on pastures contaminated by sewage.
Taenia saginata				"Beef measles" or bovine cysticercosis, which may require condemnation or freezing of beef carcasses found to be affected.
***Taenia* spp.**	Taeniasis (tapeworm infection), neurocysticercosis	--	--	Taenia cysts in cattle and swine can result in the condemnation of carcasses at slaughter and require actions such as cooking or freezing and epidemiological follow-up. Undercooked meat is a source for people.
***Trichuris* spp.**	Trichuriasis (whipworm infection)	Up to 10^2	Culture/ direct count	Trichuriasis in livestock. Probably not important as there is a probable high degree of species specificity.

[a] Most helminths of importance in animal production are not found in sewage, such as Gastrointestinal nematodes (e.g., Ostertagia ostertagi, Cooperia oncophora, Teladorsagia circumcincta, Haemonchus contortus), Liver fluke (Fasciola hepatica), and Lungworm (Dictyocaulus viviparus) in ruminants (Charlier et al., 2014).

Table 4B-3: Infectious Protozoa that Are Potentially Present in Untreated (Raw) Wastewater

Pathogen (Protozoa)	Human Health Disease	Quantity in Raw Wastewater (per liter)	Method of Quantification	Relevance to Livestock
Cryptosporidium hominus	Cryptosporidiosis, diarrhea, fever	Up to 10^4	Culture/ direct count	Not important.
Cryptosporidium parvum	Cryptosporidiosis, diarrhea, fever	--	Culture/ direct count	Cause of diarrhea and death, especially in young calves, but also in lambs, kids, foals, and piglets.
Cyclospora cayetanensis	Cyclosporiasis (diarrhea, bloating, fever, stomach cramps, and muscle aches)	Low, ~1[a] (Sturbaum et al., 1998)	--	Unknown cross-species potential. Causes diarrhea and emaciation in calves. Reported in poultry.
Entamoeba	Amebiasis (amebic dysentery)	Up to 10^2	Culture/ direct count	Unknown significance. Reported in ruminants and swine; however, because these pathogens are very host specific, a human amoeba will likely not impact animals.
Giardia spp.	Giardiasis (gastroenteritis)	Up to 10^5	Culture/ direct count	Cause of diarrhea in young animals.
Microsporidia	Intestinal microsporidiosis and diarrhea in immunocompromised persons.	--	--	Pigs often asymptomatic. In cattle, clinical signs include fever, inappetence, diarrhea, ptyalism, reduced milk production, oral ulcers and mucosal lesions. (Baker, 1995).
Neospora caninum	--	--	--	Abortion in cattle and small ruminants. Neurological disease in calves. Dog and coyote feces in sewage could cause a problem. Horses and chickens also can be infected, but the significance is not known.
Toxoplasma gondii	Toxoplasmosis, miscarriage and birth defects.	Low, as from cat litter	--	Toxoplasmosis: abortion and encephalitis in small ruminants and swine. Zoonotic risk from undercooked meat. Cat feces in sewage could cause a problem.

[a] Data from a region with expected higher background than California.

Note: The dash "—" represents a lack of data or information as related to animal health.

Table 4B-4: Infectious Viruses that Are Potentially Present in Untreated (Raw) Wastewater

Pathogen (Virus)	Human Health Disease	Quantity in Raw Wastewater (per liter)	Method of Quantification	Relevance to Livestock
Adenovirus	Respiratory disease, eye infections, gastroenteritis (serotype 40 and 41)	Up to 10^6	Molecular	Probably not important as adenoviruses are relatively host-specific. Gastrointestinal and respiratory disease in cattle, sheep, horses, and swine. Abortion in pigs. Encephalitis and hepatitis in goats. Aviadenovirus: Splenomegaly, enteritis, egg drop syndrome, bronchitis, pulmonary edema, and congestion in poultry – avian specificity (not zoonotic).
Astrovirus	Gastroenteritis	--	--	Probably not important as astroviruses are believed to be species specific (but swine astrovirus is similar to human). Diarrhea and encephalitis in cattle. Gastroenteritis in sheep, swine, and poultry.
Caliciviruses (including Norovirus and Sapovirus)	Gastroenteritis	Up to 10^9 (average 10^6)	Molecular	Gastroenteritis in swine and cattle. Human noroviruses have been detected in swine and cattle. Sapovirus has been detected in swine. Vesicular Exanthema of Swine is caused by Sea Lion Calicivirus in pigs and is important because it mimics symptoms of Foot-and-Mouth Disease.
Coronavirus	Gastroenteritis	--	--	May be important as some Coronaviruses are known to jump species. Enteritis in cattle (bovine coronavirus, or BCV) and swine (transmissible gastroenteritis virus, or TGEV). Respiratory disease in camelids (Middle East respiratory syndrome coronavirus, or MERS CoV.)
Herpesviruses	---		---	Marek's Disease is a herpes virus infection in chickens and (rarely) turkeys can cause paralysis, lesions, and mortality in some cases. Equine Herpes Virus (EHV-1) infection in horses can cause respiratory disease, abortion in mares, neonatal foal death, and/or neurologic disease.

Pathogen (Virus)	Human Health Disease	Quantity in Raw Wastewater (per liter)	Method of Quantification	Relevance to Livestock
Orthomyxovirus (includes Avian, Swine, Equine, Canine, and Human Influenza viruses).	Respiratory disease, death, pandemic potential	--	Molecular	Influenza viruses cause respiratory, gastrointestinal, and systemic febrile disease in various hosts. Highly Pathogenic Avian Influenza is an emergency condition reportable to the CDFA within 24 hours of discovery. Cross-species transmission occurs between people, swine, and poultry. Respiratory and gastrointestinal disease in poultry and swine. Unknown risk for newly discovered Influenza D in ruminants and swine.
Parvovirus	Gastroenteritis	--	--	Likely not important. Goose parvovirus is a cause of diarrhea, anorexia, respiratory disease, and death in waterfowl (i.e., geese, ducks), but the only risk is from contamination of sewage by wild waterfowl. Swine parvovirus causes abortion but is species specific.
Picornaviruses (including Aichi virus)	Gastroenteritis	Up to 10^6	Molecular	--
Enteroviruses (polio, echo, coxsackie, new enteroviruses, serotype 68-71)	Gastroenteritis, heart anomalies, meningitis, respiratory illness, nervous disorders, others	Up to 10^6	Culture/ Molecular	Duck Viral Hepatitis (Aviahepatovirus) could be a problem if wild waterfowl fecal matter gets into sewage. Seneca Valley Virus – vesicular lesions and lameness in swine (it could be problem if effluent from slaughterhouse or research laboratories enter sewage). Foot-and-Mouth Disease Virus – vesicular disease-causing cardiomyopathy and death of calves (not present currently but devastating to the livestock industry if introduced to the United States). Massive trade bans.
Hepatitis A and E virus	Infectious hepatitis	--	Molecular (Ianconelli et al, 2017)	Swine may be an important reservoir for human infection.
Polyomavirus	Progressive multifocal leukoencephalopathy (PML)	Up to 1	Molecular	Polyomavirus of birds is not important (species barrier).
Rotavirus	Gastroenteritis	Up to 10^5	Molecular	Gastroenteritis

Note: The dash "—" represents a lack of data or information as related to animal health.

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APPENDIX 4C: PATHOGENS OF CONCERN TO LIVESTOCK HEALTH

4C.1 Categories of Pathogens that may Affect Livestock

Preventing infections among and between herds is essential in maintaining a successful livestock industry. For that reason, communicable diseases such as BSE, *bovine tuberculosis*, and *bovine brucellosis* are managed through federal and state cooperative surveillance programs. These existing models for interstate collaboration may be appropriate to evaluate the risks and consequences of using DTRW as drinking water for non-dairy livestock. Also, while such interstate issues are a challenge for producers and regulators, veterinarians view the *worst-case* scenario to be the introduction of a novel strain of pathogen from the human population. Examples would be new strains of *Salmonella* or Antimicrobial Resistant (AMR) Bacteria appearing in livestock or poultry that have never been described in those host species before. These novel bacterial strains could become established in domestic livestock and become a new reservoir of food-safety and public health consequence.

Other potentially adverse events include anthropozoonotic reintroduction of pathogens that are nearly eradicated from the livestock population, such as M. bovis, which could cost millions of dollars to address. Once an animal is infected, that animal can spread infection to other susceptible animals within the herd; the damage may be amplified if the infected herd infects other herds through livestock sales, fence line contact, shared equipment, or movement of livestock or wildlife. The State Water Board's pathogen reduction crediting system is an effective approach to help ensure that drinking water is protective of public health; however, from a veterinary standpoint, the concern is the pathogens that remain in DTRW after treatment, not the number of pathogens removed from raw wastewater. Both log removal performance and final effluent concentrations are included in this report.

Descriptions of pathogen classes of concern to livestock health (including virus, bacteria, protozoa, fungi, helminths, and prions) are provided in this section.

Viruses

Hepatitis E viruses (HEV). These non-enveloped single-stranded RNA viruses are a recent emerging group of pathogens. Swine are known to be a source of Hepatitis E for people, and people to be a source for swine. Chicken Hepatitis E viruses are believed to not be transmissible to people as researchers were unable to experimentally infect Rhesus macaques. It is not known whether Hepatitis E virus transmission is possible between people and other livestock hosts, such as cattle, horses, sheep, goats, and camels.

Influenza viruses. Avian Influenza, Swine Influenza, Equine Influenza, Canine Influenza, and Human Influenza viruses are included in this list. The recently emergent feline influenza described in New York City is a cat-adapted strain of Avian Influenza that acquired the ability to readily transmit between mammals. Highly Pathogenic Avian Influenza is an emergency condition reportable to CDFA within 24 hours of discovery. Influenza viruses are known to cause respiratory, gastrointestinal, and systemic febrile disease in various hosts. Respiratory signs usually predominate in mammalian hosts. Avian influenza viruses are known to survive in surface water for extended periods of time. Presumably,

influenza viruses would be killed during the treatment process as they are enveloped and susceptible to chlorine disinfection. Avian flock biosecurity plans already discourage the use of untreated surface water in poultry farms. Biosecurity practices also should discourage the use of any open-air water supply potentially exposed to wild waterfowl.

Reovirus. Human reovirus is transmitted to cattle and possibly other livestock animals (Rosen and Sbinanti, 1960). It is the most commonly detected virus in treated wastewater after secondary treatment, UV light disinfection, chlorination, and ultrafiltration, and in heavily chlorinated treated wastewater (Betancourt and Gerba, 2016). Researchers supported by EPA and water industry groups identified reoviruses in surface water sources used for drinking water and in recreational waters, and proposed reoviruses as a useful indicator for fecal pollution (Spinner and Di Giovanni, 2001). Avian reovirus may be responsible for viral arthritis and other disease syndromes in poultry (Jones, 2000).

Bacteria

Salmonella spp**.** Group D Salmonella are responsible for diarrhea, fever, abortion, and sepsis in cattle, swine, and horses. The pathogen is not endemic to California livestock. For instance, epidemiological studies conducted along the central cost of California during the past decade (Gorski et al. 2011) identified *Salmonella* in only 0.13 percent (1/795) of cattle tested. More recently, a cross-sectional study of 20 cattle herds in locations across California (in Butte, Contra Costa, Humboldt, Kern, Lassen, Madera, Modoc, Mono, San Joaquin, San Luis Obispo, Solano, Stanislaus, Tulare, and Yuba Counties) that evaluated 1,412 cows and calves detected *Salmonella* in only 0.3 percent (4/1412) of beef cattle feces at the time of sampling (Table 1 from Flores, 2014). The concern is that chronic exposure of California cattle herds to DTRW could create a higher cumulative risk of infection for *Salmonella enterica* in cattle. *Salmonella* spp. may also affect poultry (*S. enteriditis*, S*. heidelberg,* etc.) and may require product recalls. *S. enteriditis* prevention activities are mandatory in California, where poultry producers have invested in strategies to reduce exposure to all *Salmonella* spp., including via water. In 1990, a new strain, *Salmonella enteritidis* phage type 4, was detected in people in Southern California and became the predominant serotype in patients. In 1994, the phage type 4 was detected in a Southern California egg-laying chicken ranch; the most probable source was a creek fed with wastewater effluent from a nearby treatment plant (Kinde et al., 1996).

Mycobacterium tuberculosis (MTB) complex. The MTB complex includes several species of concern for animal health (*M. tuberculosis*, *M. bovis* (including the Bacille Calmette-Guérin, or BCG strain), *M. caprae*, *M. orygis*, *M. pinnipedii*, *M. africanum*, *M. microti*, *M. canetti*, *M. suricattae*, and *M. mungi*). Among these, the most important for livestock health in North America are *M. tuberculosis* and *M. bovis*. Livestock are thought to be relatively resistant to infection with *M. tuberculosis*, although transmission to cattle from people has been reported (Ocepek et al., 2005). Cattle, however, are highly susceptible to *M. bovis*, the cause of bovine tuberculosis. *M. bovis* has long been a recognized zoonosis and is the original reason for the pasteurization of milk. Bovine tuberculosis is a regulatory condition reportable to CDFA within 2 days of discovery in California. Recently, evidence is mounting that *M. bovis* also is an anthropozoonotic, meaning people can serve as a source of infection for cattle (Robbe-Austerman, personal communication). Since the implementation of the Bovine TB eradication program in 1917, the United States has reduced the herd prevalence of Bovine TB in cattle to nearly zero; however, reservoirs of *M. bovis,* including in white-tailed deer in Michigan, complicate eradication

efforts (Ramsey et al., 2016). Although currently class "Free" for *M. bovis* in cattle, California has the highest rate of *M. bovis* in people among the 50 states and half of the total human cases in the United States. This high rate is primarily due to consumption of unpasteurized milk products from outside the United States (Harris et al., 2007). About 4 percent of human tuberculosis cases in California are caused by *M. bovis*, with cases more concentrated in Southern California (CDC, 2015, and CDPH, 2015).

Nontuberculous Mycobacterium (NTM). The worldwide incidence of non-tuberculous mycobacteria (NTM) diseases is increasing. A 2017 study in the United Arab Emirates (UAE) detected clinically and environmentally relevant NTM in treated municipal wastewater; the study emphasized the need for pathogen monitoring of treated wastewater in arid regions in which water is recycled for potable and non-potable use (Amha et al., 2017).

Clostridium perfringens. *C. perfringens* is the cause of enteritis and hemorrhagic enterotoxemia in cattle, sheep, goats, and horses. Type A causes disease in cattle and "yellow lamb disease" in nursing lambs. Type B causes "lamb dysentery" in lambs less than 2 weeks old and diarrhea in calves and foals. Type C causes hemorrhagic toxemia in sheep, hemorrhagic enteritis of calves, lambs, and suckling pigs. Type D causes enterotoxemia ("pulpy kidney disease") in sheep, goats, and cattle. Type E causes dysentery and enterotoxemia in calves and lambs. The natural reservoirs are the soil and intestinal tracts of people and animals. Humans harbor higher numbers of Clostridia bacteria than cattle and poultry. Some people shed large numbers in their feces. *Clostridium perfringens* is more resistant to wastewater treatment than indicator microorganisms.

Campylobacter jejuni. *Campylobacter jejuni* is a cause of enteritis in calves, heifers, and young horses. In sheep, it may cause abortions, stillbirths, and weak newborn lambs. It also causes diarrhea in 3-day old chicks. Poultry (chickens, turkeys, ducks, and pigeons) are an important reservoir host for human foodborne infections. Human feces and slaughterhouse effluents could be important sources of the pathogen in wastewater.

Antimicrobial Resistant Bacteria. Antibiotic resistant bacteria and genes are ubiquitous in wastewater and the environment. Antimicrobial resistance (AMR) in bacteria infecting livestock and people is monitored by the CDFA Antimicrobial Use and Stewardship program. Please see **Appendix 4A** for descriptions of these pathogens and more information on the significance of ARB in recycled water that are of concern to livestock health. In recent years, a number of studies have focused on the potential threats of ARM to animal and human health. Although Animal husbandry practices and hospitals have both been identified as important sources of residual antibiotics (Tao et al., 2014; Varela et al., 2013), the fate and transport of these pathogens through WWTPs is not well understood and are influenced by local variables, including source water quality, seasonal variations in wastewater flows, treatment processes employed, and land application of treated wastewater and biosolids (McKinney and Pruden, 2012; Negreanu et al., 2012; Rubiano et al., 2012; Munir and Xagoraraki, 2011). Although a number of studies have demonstrated that AMR bacteria may proliferate in drinking water distribution systems, as well as in WWTPs, other studies have observed a reduction in ARM (Kim et al., 2010; Xi et al., 2009).

Protozoa

Cryptosporidium parvum. This pathogen causes severe diarrhea in young calves, lambs, goat kids, and foals, and can also affect swine. *C. parvum* is zoonotic and transmissible between people and calves. Like

Salmonella, C. parvum is not endemic to California livestock, as demonstrated by Gorski et al. in a cross-sectional study of 20 cattle herds from across California. This study included a molecular characterization of the 18S SSU rRNA gene for 81 isolates of *Cryptosporidium* from these cattle; none was confirmed as *C. parvum.* Researchers working in Australia recently reported that the risk of oocyst infectivity for WWTPs analyzed was significantly lower than previously thought and noted that including oocyst infectivity in guideline values and in quantitative microbial risk assessment (QMRA) could affect treatment requirements and costs (King et al, 2017). The same study also found that oocysts persisting in the secondary treated clarified effluent were more infectious than those detected in the raw sewage, thereby raising questions about the risk to livestock following a community outbreak.

Neospora caninum. This definitive host of this protozoa is the dog. Neospora caninum is passed fecal-oral from dogs to cattle and, rarely, to sheep and goats. It is a major cause of cattle abortion in California. Infectious oocysts could be present in wastewater in cases where dog feces enter municipal sewage, which can occur when owners flush dog feces down the toilet and after storms when dog and coyote feces enter storm drains that are connected to municipal sewage systems

Toxoplasma gondii. The definitive host of this protozoa is the cat. Toxoplasma gondii is passed fecal-oral from cats to sheep, goats, and people (but rarely to cattle). It is a common cause of abortion in sheep and goats and can cause miscarriage and birth defects in people. Humans are not a source of the infection for livestock. Infectious oocysts could be present in wastewater in cases where cat feces enter municipal sewage, which can occur when cat owners flush cat feces down the toilet, after storms when cat feces enter storm drains that are connected to municipal sewage systems, and on rare occasions where cats are trained to use the toilet.

Fungi

Microsporidia. *Encephalitozoon intestinalis* is on the EPA's Contaminant Candidate List for emerging waterborne pathogens and is a concern for both livestock and human health (John et al., 2005). Although this species may be removed by drinking water treatment systems, it is resistant to chemical disinfection (Gerba et al., 2003a; Gerba et al., 2003b). Numerous strains of microsporidia have been detected in the feces of cattle, swine, goats, horses, and chickens, but no clinical cases have yet been reported for cattle or swine (Stentiford et al., 2013).

Helminths

Taenia solium and T. saginata: Humans are the definitive hosts for both these tapeworms. Humans are infected by consuming raw or undercooked pork (*T. solium*) or beef (*T. saginata*). Humans also can serve as the intermediate host for *Taenia solium*; infection can lead to cysticercosis, a disease that can cause seizures (CDC, 2013). The normal intermediate host for *T. saginata* is cattle, and the intermediate stage causes "beef measles," or bovine cysticercosis. Neither people nor cattle are usually seriously affected by *T. saginata*. The principal consequence is economic, with condemnation or required freezing of beef carcasses found to be affected at slaughter. On the other hand, *T. solium* is the cause of porcine and human cysticercosis. Porcine cysticercosis may simply require condemnation or freezing of pork carcasses found to be affected at slaughter. In people, *T. solium* infection can cause neurocysticercosis, or tapeworm cysts in the brain and ophthalmic cysticercosis of the eye. In addition to raw pork, people can be infected by fecal-oral transmission from another human and even from themselves, with

resulting cysticercosis. Tapeworm eggs present in human feces are the source of infection for cattle and swine. Cysticercosis has been associated with feeding cattle on pastures contaminated by sewage.

Prions

Bovine Spongiform Encephalopathy (BSE): Also known as Mad Cow Disease, BSE is a degenerative and fatal neurological disease and been transmitted to cattle herds through contaminated feed manufactured from the carcasses of infected mammals. Numerous teams in Europe have studied variables related to transmission of these microbes due to the seriousness of the disease, implications for livestock health, and the history of infection in the United Kingdom. The reports issued thus far have identified risks related to the management of domestic and industrial wastewater. For example, researchers in the UK assessed the risk of infection of cattle foraging on crops fertilized with sewage sludge and used a model to predict that the risk of BSE transmission for cattle grazing these crops would be approximately 7×10^{-5} cows per year, which is not high enough to sustain an endemic level of BSE in the UK cattle population (Gale and Stanfield, 2001). Another research team in Europe evaluated BSE in wastewater samples over 6 years and observed that BSE is not reliably removed or inactivated by conventional wastewater treatments that have low retention times (Marin-Morenoa et al., 2016). More research is necessary to determine the most effective treatment processes to control prions in wastewater effluent. In the United States, numerous research studies focused on the persistence of prions in wastewater and sewage. Prions can survive in wastewater for weeks (Miles et al., 2011) and are prevalent in waste from slaughterhouses that process both domestic livestock and wild game, and in wastewater produced by taxidermy operations. The prevalence of BSE in cattle historically has been so low that it is difficult to quantify, and researchers have modeled the risk of infection to be approximately 0.167 cattle per million (Gale and Stanfield, 2001). Although the United States cattle population has not experienced a major outbreak of BSE, researchers stress that it is important to continue to monitor prions in livestock populations and to periodically conduct risk assessments.

4C.2 Additional Pathogenic Microorganism Reduction

Exposure due to livestock watering is likely very low and not a significant risk if undertaken in compliance with the BMPs recommended in this report, which will ensure the production of recycled water that meets or exceeds existing EPA regulations for pathogen concentrations for safe drinking water. Furthermore, the Panel's evaluation of additional human and animal pathogens concluded that DTRW will not significantly increase the risk of infections compared to existing drinking water sources. The Panel also emphasizes that the drinking water exposure route may be negligible compared to dust/soil/excreta exposure routes that likely dominate in animal feeding operations.

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APPENDIX 4D: COMPARING PATHOGEN RISKS IN DRINKING WATER TO DTRW

4.D.1 Bacterial Risks in Disinfected Tertiary Recycled Water

Salmonella enterica causes 1.2 million acute gastrointestinal illnesses in the United States each year (Scallan et al., 2011; CDC, 2018) and is a common cause of foodborne illness. Based on recent evaluations, concentrations of *Salmonella* spp. in raw wastewater average approximately 1,000 MPN/L (Schoen et al., 2017; Trussell et al., 2013). As shown in **Table 4D.1**, DTRW will provide at least 8.7-$\log_{10}$ reduction in total coliform; given the similar sensitivities of the *Salmonella* spp. and total coliforms, an equivalent level of *Salmonella* reduction also can be assumed. Based on this degree of treatment, effluent concentrations of *Salmonella* spp. should be less than 2×10^{-6}/L. Because this value is below the one in 10,000 (or 10^{-4}) infection health-based target for humans (1.8×10^{-5}/L), the Panel concluded that the concentrations of *Salmonella* spp. will meet requirements for safe municipal drinking water. Accordingly, Salmonella spp. will represent a minimal increased risk to livestock and human health through the use of DTRW.

Table 4D.1: Estimated Concentrations of *Salmonella Enterica* in Untreated Wastewater and Reductions through Treatment

Salmonella enterica Raw Wastewater Concentration (MPN/L)	Log10 Removal	Title 22 Effluent Concentration (MPN/L)	Human drinking water target (MPN/L)
1,000 (average)	8.7	2.0E-06	1.80E-05

Campylobacter spp. causes 1.3 million acute gastrointestinal illnesses in the United States each year (CDC, 2017a). The primary vehicle for transmission is foods of animal origin, including poultry and raw milk. In the *Australian Water Recycling Guidelines*, the 95th percentile value for *Campylobacter* spp. concentrations in raw wastewater was 7,000 MPN/L (NRMMC et al., 2008). Similar values were reported in Schoen et al. (2017). Based on an estimated 8.7-$\log_{10}$ bacterial reduction through DTRW, the effluent *Campylobacter* concentrations would be about 1.4×10^{-5}/L, which is similar to the health-based target for human consumption (1.44×10^{-5}/L). Because this pathogen is reduced to acceptable drinking water values, the Panel concluded that *Campylobacter* spp. will represent minimal increased risk to livestock watering and human health through the use of DTRW.

Table 4D.2: Estimated Concentrations of Campylobacter spp. in Untreated Wastewater and Reductions through Treatment

Campylobacter spp. Raw Wastewater Concentration (MPN/L)	Log_{10} Removal	Title 22 Effluent Concentration (MPN/L)	Human drinking water target (MPN/L)
7,000 (95th percentile)	8.7	1.4E-05	1.44E-05

Clostridium perfringens* and *Mycobacteria. Spores of the anaerobic bacterial species *Clostridium perfringens* average approximately 10,000 CFU/100 mL in raw sewage, and Title 22 treatment of DTRW would remove at least 2-$\log_{10}$ prior to disinfection, with UV providing an additional 2-$\log_{10}$ reduction (Guimaraes 2016). It is important to note that like other fecal indicator bacteria, most strains detected in sewage are not pathogenic: less than 10 percent would contain one or more of the known five toxin genes required for potential pathogenicity (Chern et al. 2014). While viable spores will persist after treatment, they may be fewer than 0.01 per liter, which is a very low dose and may not be infectious in animal hosts. The *Mycobacteria* are removed in a manner similar to the total coliform, *Salmonella*, and *Campylobacter spp.*, to the minimum 8-9 $\log_{10}$ reduction through DTRW treatment. Furthermore, using Title 22-compliant UV disinfection should provide a significant additional barrier to *Mycobacteria*, given their high sensitivity to UV irradiation. Doses of 20 mJ/cm^2 have been shown to provide more than 6-log inactivation of Mycobacteria (Hayes et al., 2008). The 80-100 mJ/cm2 UV requirements, therefore, offer a robust additional barrier to both tuberculosis and non-tuberculosis mycobacteria.

Table 4D.3: Estimated Concentrations of *Clostridium Perfringens* in Untreated Wastewater and Reductions through Treatment

Clostridium perfringens Raw Wastewater Concentration (MPN/L)	$\log_{10}$ Removal with UV disinfection	Title 22 Effluent Concentration (MPN/L)	Fraction containing toxin genes	Fraction pathogenic to animals	Concentration containing toxins pathogenic to animals (MPN/L)
10,000 (all toxin and non-toxin-producing strains)	4	1	10%	10%	0.01

4.D.2 Pathogenic Protozoa Risks in Disinfected Tertiary Recycled Water

Giardia lamblia. This parasitic protozoan is often detected in cattle feces (some 6- to 60-percent prevalence, typically higher in young animals), but is of unknown animal health significance and presents both with and without gastrointestinal symptoms in different animals (Minetti et al., 2014). Given an average of 200 cysts per liter in raw sewage and at least $\log_{10}$ 9.3 removal by Title 22 treatment with UV disinfection (see **Table 4D.4**), the remaining cysts would be (1.0 x 10^{-7}/L) under median concentrations and (2.0 x 10^{-6} / L) under extreme (90th percentile) concentrations. Because both values are below the safe drinking water level (6.8 x 10^{-6} / L), the Panel believes DTRW will not significantly increase the risk of *Giardia* infections compared to existing potable sources.

Table 4D.4: Estimated Concentrations of *Giardia lamblia* in Untreated Wastewater and Target Reductions Achieved through DTWR Treatment

Giardia lamblia Raw Wastewater Concentration (cysts/L)	$\log_{10}$ Removal	Title 22 Effluent Concentration (cysts/L)	Human Drinking Water Concentration (cysts/L)
200 (average)	9.3	1.0E-07	6.80E-06

Cryptosporidium parvum. Humans are affected by and excrete *Cryptosporidium hominis.* The animal-infectious zoonotic species, *C. parvum,* is a minor representative in raw sewage (<10 percent). Assuming there are 10 total oocysts/L in raw wastewater, applying: (a) 8.5 $\log_{10}$ reduction for Title 22 treatment

with UV disinfection, and (b) conservatively assuming 10 percent is potentially infectious in animals, the resulting value in DTRW is 3.2 x 10^{-9} / L. Because this concentration is orders of magnitude lower than what is considered safe for human drinking water (< 1.7 x 10^{-6} / L), the Panel concluded that DTRW should not significantly increase the risk of *Cryptosporidium* infection for either livestock or the people consuming their products.

Table 4D.5: Estimated Concentrations of *Cryptosporidium Parvum* in Untreated Wastewater and Reductions through Treatment

Cryptosporidium parvum Raw Wastewater Concentration (oocysts/L)	Log10 Removal	Title 22 Effluent Concentration (oocysts/L)	Fraction of potential relevance to livestock	Concentration relevant to livestock health	Human Drinking Water Concentration (cysts/L)
10 (average)	8.5	3.2E-08	1%	3.2E-09	1.7E-06

Toxoplasma gondii is among the most common parasites found in animals and although it can be transmitted orally, epidemiologic evidence indicates that cats are an essential part of the lifecycle (Wallace, 1969; Munday, 1972). *T. gondii* can cause severe disease in goats, sheep, pigs, rabbits, minks, birds, and other domesticated animals (Dubey et al., 1997); however, given that: (1) *T. gondii* concentrations will be significantly lower than *Cryptosporidium* oocyst concentrations, and (2) the finding that *Cryptosporidium* presents a negligible impact to livestock health, *T. gondii* also should not pose a significant impact on livestock health. Nevertheless, the Panel undertook a qualitative evaluation of the health risks of *T. gondii*.

While toxoplasmosis is generally contracted by eating uncooked meat containing viable oocysts or by eating food contaminated with oocysts from the feces of infected cats, recently there have been three documented outbreaks associated with water contamination in Canada, the United States, and Brazil. The Canadian outbreak was linked to fecal contamination by wild cats in a municipal water reservoir that is used as a local drinking water supply (Bowie et al., 1997). The outbreak in the United States involved the widespread infection of marine mammals and, although no direct link was determined, it was concluded that coastal waters contaminated by cat excrement in runoff led to the outbreak (Burnett et al., 1998). While human infections of *T. gondii* are rare in the United States, serological surveys suggest high endemicity of toxoplasmosis in people (Silva et al., 2002; Dubey, 2004) in rural areas of Sao Paulo and Rio de Janeiro, Brazil. Epidemiological evidence indicated that non-disinfected drinking water contaminated with oocysts was the primary source of infection (Bahia-Oliveira et al., 2003) within this population.

Dubey et al. (2004) noted that the detection of *T. gondii* oocysts in municipal water systems is more difficult than the detection of *Cryptosporidium* oocysts because relatively few *T. gondii* oocysts are likely to be present due to their size, life stage, and susceptibility to disinfection. In a review of effectiveness of disinfectants on *T. gondii* oocysts, a range of disinfectants were found to successfully kill oocysts or render them inactive. These treatments include sulfuric acid, ethanol, ammonium hydroxide, household ammonia, physical drying, and a variety of commercial disinfectants, as well as peracetic acid and irradiation. While no specific wastewater treatment processes were evaluated, concentrations of 0.1 to

5 percent of the disinfectant(s) were used to effectively eliminate the pathogen. In comparison, disinfection to reduce the infectivity of *Cryptosporidium parvum* indicated similar trends, with exposure to low dosages of hydrogen peroxide and/or ammonium hydroxide effective at reducing *Cryptosporidium* infectivity 1,000-fold (Weir, 2002).

The Panel concluded that *T. gondii* represents minimal increased risk to livestock watering and human health through the use of DTRW because cats are the only known hosts that excrete environmentally resistant oocysts, and the oocysts are inactivated with UV disinfection.

Neospora caninum is dependent on a domestic animal for its lifecycle, with canines as the only definitive hosts. *N. caninum* is excreted in the feces of dogs and coyotes and sporulate outside the host. Nothing is currently known about the survival of the resistant stage of *N. caninum* oocysts in the environment; however, because of its close relationship with *T. gondii*, it is assumed that the survival and disinfection of *N. caninum* oocysts is similar to that of *T. gondii* oocysts (Dubey, 2004). Additional research (Dubey, 2003) indicates that *N. caninum* is one of the most efficiently transmitted parasites of cattle, and up to 90 percent of cattle in some herds are considered infected; some dairies demonstrate up to 87 percent of cows as seropositive. Transplacental transmission currently is considered the major route of transmission, and neosporosis is one of the leading infectious causes of abortion in cattle worldwide (Dubey et al., 2007).

While neosporosis is a major disease in cattle, there currently is no evidence in the literature for human infection; therefore, zoonotic potential is uncertain. To date, clinical neosporosis has been reported in sheep, goats, deer, rhinoceroses, and horses, and antibodies to *N. caninum* have been found in water buffaloes, red and gray foxes, coyotes, camels, and cats.

As stated above, there has been evidence of *T. gondii* (often misidentified as *N. caninum*) being found more frequently in animals downstream of infected watersheds, suggesting that infective oocysts may be transported in stormwater runoff. Because of their similar morphology, *N. caninum* oocysts also might be washed downstream and accumulate in the environment in areas where infected cattle or water buffaloes reside (Neverauskas et al, 2015).

Similar to *T. gondii*, because of the fact that canines are the only known hosts that can excrete environmentally resistant *N. caninum* oocysts, because of their assumed similar level of disinfection, and because of their relationship to well understood pathogens such as *Cryptosporidium*, the Panel concluded that *N. caninum* represents minimal increased risk to livestock watering and human health through the use of DTRW.

4D.3 Enteric Virus Risks in Disinfected Tertiary Recycled Water

Hepatitis E virus type 3 can infect both people and swine, so its presence in raw wastewater could lead to infections in animals ingesting DTRW and people consuming pork. Other groups of Hepatitis E can affect poultry. Concentrations of Hepatitis E in raw wastewater averages 1,200 genome copies (GC) per liter (Hellmér et al., 2014). Through DTRW, these concentrations will be reduced by 8.7-$\log_{10}$, assuming Hepatitis E is reduced similarly to other enteric viruses (see **Table 4D-6**). Accordingly, effluent concentrations of Hepatitis E will be approximately 2.4E-06 GC/L. To translate from GC to infectious units (IU), a conservative ratio of 10 GC per 1 IU would lead to an effluent concentration of 2.4E-07 IU/L.

This level of reduction would be sufficient to protect against even the most highly infective human viruses, such as rotavirus, which requires levels of 2.2E-07 IU/L to achieve the risk goal of 1 in 10,000 illnesses per year.

Furthermore, the previous discussion demonstrated that DTRW treated to Title 22 standards would also reduce enterovirus concentrations to acceptable drinking water levels. According, the Panel believes that DTRW will not be a significant source of either Hepatitis E or enterovirus infection for livestock or people.

Table 4D-6: Estimated Concentrations of Hepatitis E in Untreated Wastewater and Reductions through Treatment

Hepatitis E virus Raw Wastewater Concentration (GC/L)	Log_{10} Removal	Title 22 Effluent Concentration (GC/L)	Ratio of GC-to-IU	Title 22 Effluent Concentration (IU/L)	Human drinking water concentration (IU/L)
1,200 (average)	8.7	2.4E-06	10:1	2.4E-07	2.2E-07

4.D.4 Microsporidia Risks in Disinfected Tertiary Recycled Water

Microsporidia would be expected to be removed in a manner similar to the bacterial species discussed above. Furthermore, the requirement for UV disinfection in the 80-100 mJ/cm^2 range should provide a robust degree of inactivation given the high UV susceptibility of microsporidia, ~1.5-log_{10} inactivation for a dose of 3 mJ/cm^2 (Huffman, 2002). The Panel concludes that the use of DTRW will not significantly increase the risk of *Microsporidia* infections for either livestock or human health.

4.D.5 Other Viral Pathogen Considerations

While the organisms in **Table 4-2** were the focus of the Panel's evaluation, a comprehensive summary of the types and quantity of microorganisms that are infectious to people and potentially present in untreated wastewater is provided in **Appendix 4B**, which is based on Table 6-2 in the EPA's *2012 Guidelines for Water Reuse* (EPA, 2012). The Panel modified this table to be relevant to livestock watering.

Hepatitis E. The Panel evaluated Hepatitis E virus but did include avian influenza among the pathogens of concern based on a recent WHO review that concluded, "Information on the excretion of H5N1 viruses in urine or faeces by mammalian species, including humans, is exceedingly limited and unlikely to be representative of a potential future human pandemic strain" (WHO, 2007).

Reovirus. Reovirus was also considered as a potential pathogen of concern because of its: (a) prevalence in treated effluents, (b) resistance to chlorine, and (c) small size, which may allow it to pass through physical removal processes. Because of its lower association with animal and human health issues, however, it was not carried forward in the evaluation of health risks. Its properties, however, make it an attractive option for use as an indicator of unit process performance.

Helminths. Helminths were not included because those of importance in animal production, such as the trematodes, Taenia solium and Taenia saginata, generally are not found in human sewage (Charlier et

al., 2014). As discussed in Section 4.1.1, these organisms are effectively removed by primary and secondary wastewater treatment. One potential exception is wastewater that contains abnormally high concentrations of helminth ova, such as slaughterhouse wastes. One strategy for preventing this occurrence is to implement a source control program to exclude such waste streams from the water recycling facility.

Prions. Prions were not included because of: (a) expected low occurrence in wastewaters, and (b) a high degree of removal through the wastewater treatment process. Accordingly, the levels of prions expected in the treated effluents would not pose a significant risk to animal or human health. One potential exception is wastewaters containing high concentrations of animal tissue, such as slaughterhouse wastes. One strategy for preventing this occurrence is to implement a source control program to exclude such waste streams from the water recycling facility.

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APPENDIX 5A: EXAMPLE CALCULATIONS FOR CHEMICALS

The Panel prepared the following calculations, which were conservative in nature and designed to reflect absolutely worst-case scenarios. With respect to human exposure to residues, for example, the Panel used the highest concentrations of a given chemical reported in DTRW, assuming 100-percent bioavailability with 100 percent of an ingested dose accumulating in either muscle or eggs. The Panel used available information to estimate daily water intake and muscle mass or egg production. The most conservative human benchmark was used to compare against estimated residue intakes. The Panel realized that there could be variations in estimated residues depending on the assumptions used. Two scenarios of livestock exposure served as examples: (1) a 364-kg feedlot steer, and (2) 1.6- to 1.9-kg laying hen producing four eggs per week. Similar calculations could be made for other species and productivity scenarios.

For the meat and egg concentration estimates, the Panel did not consider physiologic pharmacokinetic modeling, which might be warranted for select compounds that approach concentrations of concern or have long half-lives. Daily food consumption values for edible tissues were determined to be 300 grams meat and 100 grams of eggs per person per day (FDA CVM, 2016).

5A.1 Triclosan

Triclosan is a halogenated phenol that is used as a broad-spectrum antimicrobial. It is found in many consumer and commercial products. Consumer products contain 0.1- to 0.3-percent triclosan (1 to 3 parts per thousand). The chemical is not highly regulated and has low acute toxicity; however, it is a possible endocrine disruptor (thyroid and estrogenic effects have been noted). It is not considered to be genotoxic, mutagenic, or carcinogenic. Bioaccumulation has been noted in aquatic species although it has low water solubility and a log K_{ow} of 4.76. It persists in biosolids. Kinetic studies in people and animals indicate that triclosan has a relatively short-half life and does not accumulate in tissues. It is a widespread contaminant of surface waters and has been found in 57.6 percent of streams and rivers sampled. WWTP removal is variable (Dann and Hontela, 2011). Dioxins, 2,4-dichlorophenol, and 2,4,6-dichlorophenol are transformation products. One interesting note is that triclosan might prime bacteria for antibiotic cross-resistance.

Concentrations of triclosan in WWTP effluents in the United States range from 0.03 to 2.7 µg/L (Dann and Hontela, 2011); the 90th percentile concentration of triclosan in DTRW from California was reported by Anderson et al. (2000) at 0.485 µg/L. A conservative human benchmark dose level of 47 mg/kg has been recommended (Rodricks et al., 2010). An ADI of 0.05 mg/kg has been suggested.

Water intake for livestock varies depending on age, productivity, pregnancy/lactation status, diet, and ambient temperature. For the purposes of calculating a dosage for a 364-kg (800 lb) feedlot steer in 90°F weather, an estimate of water intake was 65.9 liters per day (Meehan et al., 2015). Assuming a triclosan water concentration of 0.485 µg/L, the daily dosage of triclosan would be 0.088 µg/kg (a total dose of 32 µg). This exposure is very low compared to the benchmark dose modeling (BMDL) of 47 mg/kg for people. Note that daily water intake estimates can vary depending on the source of information (CCME,

1993; Ward and McKague, 2007). Because triclosan is not bioaccumulative in animals, triclosan residues in tissues were calculated as those consumed within the 24-hour period prior to slaughter.

To determine a worst-case scenario for human exposure following the consumption of an edible food product (in this case, muscle) from the steer, the Panel assumed 100-percent bioavailability with 100 percent of the dose concentrating in muscle tissue. Assuming a 65-percent muscle mass, the 364-kg steer would have 236 kg of muscle. The concentration of triclosan per kg of muscle would be 0.136 µg or 136 ng per gram of muscle. Using a human daily food consumption value for muscle of 300 grams, an ingested dose of triclosan would be 0.041 µg or 41 ng. For a 60-kg adult female, the triclosan dosage would be 0.7 ng/kg (41 ng ÷ 60 kg). This estimated worst-case intake would be approximately 73,700 times less that an ADI of 0.05 mg/kg.

Making similar calculations for poultry assumes the laying hens (1.6 to 1.9 kg) would consume approximately 0.32 liters per day at the upper end of the consumption range (OMAFRA, 2016). While individual egg production varies depending on a number of factors, the Food and Agricultural Organization of the United Nations (FAO) estimates that a laying hen would produce four eggs per week (FAO, 2003). If 0.32 liters of water containing 0.485 µg/L of triclosan was provided, then a daily dosage for a 1.9-kg bird would be 0.155 µg ÷ 1.9 kg = 0.082 µg/kg. Again, assuming 100-percent bioavailability, one egg produced every other day, and the entire 2-day dose being present in the one egg, the egg would contain 0.310 µg. Assuming the egg weighed 50 grams, the egg would contain 6.2 µg/kg of triclosan. Assuming a daily egg consumption value of 100 grams, a total human dose would be 0.62 µg or 620 ng. For a 60-kg adult female, it would equate to a daily dosage of 10.3 ng/kg body weight or approximately 4,800 times less than the human ADI of 0.050 mg/d.

5A.2 17β-Estradiol

Endocrine disrupting chemicals (EDCs) have received significant attention since Theo Colborn's groundbreaking 1996 book, *Our Stolen Future,* alerted the public to the impact of hormone-disrupting chemicals in the environment on animal and human sexual development. EDCs can be naturally occurring (e.g., 17β-estradiol) or synthetic (e.g., diethylstilbestrol, DDT, bisphenol A). The occurrence of EDC in potable water and recycled water has been reviewed (Falconer et al., 2006). Although many hormonal pathways can be impacted, the effect of chemicals on estrogen receptors has perhaps received the most attention. Chemicals with estrogenic receptor activity vary in their potency. Relative estrogenic activities are compared to that of 17β-estradiol (estrogen equivalent of 1), as shown in **Table 5A-1**.

Table 5A-1: Estrogenic Equivalents (EEQs) of Endocrine Disrupting Chemicals Compared to 17β-Estradiol Using E-Screen Cell Proliferation Assay (from Falconer et al., 2006)

Compound	EEQ[a]	Reference
Diethylstilbestrol	10	Soto et al. (1992)
17β-Estradiol	1	Soto et al. (1992)
Genistein	0.00020	Fang et al. (2000) and Koerner et al. (2001)[b]
4-tert-Octylphenol	0.000065	Fang et al. (2000) and Koerner et al. (2001)[b]
Nonylphenol	0.000003	Soto et al. (1992)
o,p'-DDT	0.000001	Soto et al. (1992)

[a] Quantification of estrogenicity: EEQ (estrogen equivalent) = $EC_{50\ ESTRADIOL}/EC_{50\ SAMPLE}$.

[b] Mean of values reported in Fang et al. (2000) and Korner et al. (2001).

Estrogenic compounds are used in livestock production to improve productivity. For example, zeranol (Ralgro®) and estradiol benzoate (Synovex®) are estrogenic compounds implanted in beef cattle to improve weight gain. Each Ralgro implant contains 36 mg of zeranol (approximately 120 days of activity), and Synovex implants can contain up to 28 mg of estradiol benzoate (up to 200 days activity). Estrogenic compounds enter water sources from wastewater effluent and animal feedlots. Estrogenic compounds, albeit of typically low potency, also are present as phytoestrogens in many plant-based human foods, including legume (sprouts) and soy products (tofu, soy sauce) (Mattison et al., 2014).

A 90th percentile concentration of 17β-estradiol in tertiary water was reported by Anderson et al. (2010) to be 8 ng/L, which is in line with other reported concentrations of 17β-estradiol in various treated water sources (Falconer et al., 2006). For the purposes of calculating a dosage for a 364-kg (800 lb) feedlot steer in 90°F weather, an estimate of water intake was 65.9 liters; therefore, a daily dose of 17β-estradiol for the steer would be 527 ng. It can be compared to 28 mg of estradiol over 200 days (Synovex product), which would translate into a daily dose of approximately 0.14 mg (140,000 ng).

Because β-estradiol is not bioaccumulative in animals, residues in tissues were calculated as those consumed within the 24-hour period prior to slaughter. Again, assuming 236 kg muscle mass with the total dose of 527 ng, there would be 2.2 ng/kg muscle. In beef cattle, estrogen-implanted animals produce meat that contains slightly more estrogen than background (1.9 versus 1.3 ng per 3 oz or 85 grams or approximately 22.3 ng/kg in an implanted steer) (Treffer, 2013); therefore, an implanted steer could contain approximately 24.5-ng estradiol/kg of muscle. It can be compared to the daily production of estrogen in a child and adult female of approximately 50,000 ng and 480,000 ng per day. One birth control pill can contain 35,000 ng of estrogen. Relative contributions of estrogen sources to total daily estrogen intake are shown in **Table 5A-2.**

Table 5A-2: Relative Contributions of Estrogen Sources to Total Daily Estrogen Intake (from Falconer et al., 2006)

Compound/s	EEQ[a]
Oral Contraceptives	16,675
Hormone Replacement Therapy	3,350
Plants and Food	102
17β-Estradiol (Endogenous)	1
Organochlorines	0.0000025

[a] Quantification of estrogenicity: estimated EEQ (estrogen equivalent) = $EC_{50\ ESTRADIOL}/EC_{50\ SAMPLE}$.

Doing similar calculations for eggs, a laying hen ingesting 0.32 liters of water per day would receive a dose of 17β-estradiol of 2.56 ng; therefore, a 50-gram egg produced every other day and containing the full 2-day dose would contain 5.12 ng of estradiol. It can be compared to an approximate estradiol content of 15 ng in the yolk (the rule of thumb is yolk constitutes 30 percent of the weight of an egg; therefore, a 50-gram egg would have 15 grams of yolk) of a 50-gram egg (Aslam et al., 2013).

The WHO ADI for estradiol is 50 ng/kg (WHO, 2000); therefore, for a 60-kg adult female, the total daily estradiol intake should not exceed 3,000 ng. Using the worst-case scenario, a meal of a single egg from a DTRW-supplied hen would provide approximately 5 ng of estradiol, whereas a meal of two eggs would provide approximately 10 ng of estradiol or a dose of about 0.2 ng/kg body weight.

Using another approach as outlined by Snyder and Benotti (2010) and considering β-estradiol as a therapeutic drug, a conservatively estimated ADI (or comparison value) was calculated to be 0.00024 µg/kg/D (0.24 ng/kg/D). If an implanted steer contained 24.5-ng estradiol/kg meat, a 60-kg female eating 300 g of meat per day would receive a daily dosage of estradiol of 0.123 ng/kg/D (24.5 ng/kg x 0.3 kg ÷ 60 kg). It is still below, but approaching, the ADI. Calculations for eggs determined an estradiol concentration of 0.10 ng/g. A 60-kg female consuming 100 grams of egg per day would receive a dosage of estradiol of 0.167 ng/kg. Again, it is still below, but approaching the ADI. Both estimates are well below the WHO ADI of 50 ng/kg. Again, the Panel's model was conservative and included implausible assumptions such as 100-precent bioavailability from DTRW, no metabolism or excretion, and 100-percent of the residue being concentrated in edible tissues such as milk or eggs.

5A.3 Boron

Boron is a naturally occurring element found in rocks, soils, and water. Boron does not exist as a pure element but has high affinity for atoms that donate electrons. Naturally occurring, boron-containing minerals are common as sodium and calcium borates, borosilicates, and boric acid. Boron concentrations in groundwater are due to leaching from rocks and soils containing the various forms of boron. The United States is the world's leading manufacturer of refined boron compounds. Mines in California produced approximately 600,000 metric tons of boric oxide in 2010 (the largest boron mine in the world is near the town of Boron, California). Boron compounds are widely used as whitening agents and in the manufacturing of many commercial products. Borate minerals are very water soluble and, once dissolved, are difficult to remove from water.

Boron does not have an existing MCL. In California, there is a notification level if concentrations exceed 1,000 µg/L (State Water Board, 2017). Boron concentrations have been determined in a number of active and standby public wells in California, with 171 of 12,158 wells having boron concentrations of >1,000 µg/L. When boron levels are >1,000 µg/L, a utility or responsible agency must report the detection to appropriate agencies. The health advisory for human non-cancer health effects is 5,000 µg/L. An Australian drinking water guideline based upon human health considerations should not exceed 4,000 µg/L.

The EPA reference dose of boron is 0.2 mg/kg/day. A recent application of new uncertainty factors to the safety assessment of boron, determined a TDI for boron of 0.13 mg/kg/day, based upon a $BMDL_{05}$ from rat developmental toxicity (Hasegawa et al., 2013). Boron is present in many foods, particularly foods of plant origin.

A safe upper limit for boron in livestock water is 5 mg/L, according to the EPA and Canadian Council of Ministers of the Environment. Cattle consuming water containing 150 to 300 mg/L exhibited toxicity signs, including decreased food consumption and weight (NRC, 2005). A maximum daily tolerable level (MTL) for animals has been proposed as reasonable (NRC, 2005). It translates into about 135 mg per kg of diet. Boron is an essential mineral for both animal and human health. Boron is almost completely absorbed from the gastrointestinal tract and is rapidly excreted via the urine (Hasegawa et al., 2013). It is widely distributed in tissues.

For the purposes of calculating a dosage for a 364-kg (800 lb) feedlot steer in 90°F weather, an estimate of water intake is 65.9 liters (Meehan et al., 2015). Data from DTRW from the City of San Diego (MWH, 2007) indicated boron concentrations of 0.275 mg/L. A beef animal consuming 66 L of DTRW containing 0.275 mg/L of boron would consume 18,150 µg of boron per day.

To determine a worst-case scenario for human exposure following the consumption of an edible food product (in this case, muscle) from the steer, the Panel assumed the ingestion of water containing boron at 0.275 mg/L, 100-percent bioavailability with 100 percent of the dose concentrating in muscle tissue. Again, because boron is not bioaccumulative in animals, boron residues in tissues were calculated as those consumed within the 24-hour period prior to slaughter. Assuming a 65-percent muscle mass, the 364-kg steer would have 236 kg of muscle. The concentration of boron per kg of muscle would be 77 µg or 0.077 µg per gram of muscle. The FSIS (n.d.) provided unpublished data to the Panel indicating that boron in 874 beef muscle samples across all production classes averaged 0.294 µg/g. Using a daily food consumption value for muscle of 300 grams, an ingested dose of boron would be 23 µg. For a 60-kg adult female, the boron dosage would be 0.385 µg/kg (23 µg ÷ 60 kg), which is approximately 340 times less than a TDI of 0.13 mg/kg.

Making similar calculations for poultry assumes that laying hens (1.6 to 1.9 kg) would consume approximately 0.32 liters per day at the upper end of the consumption range (OMAFRA, 2016). While individual egg production varies depending on a number of factors, the FAO estimates that a laying hen would produce four eggs per week (FAO, 2003). If 0.32 liters of water containing 0.275 mg/L of boron were provided, then a daily dosage for a 1.9-kg bird would be 88 µg total or ([0.275 mg/L x 0.32] ÷ 1.9 kg = 0.046 mg/kg = 46 µg/kg). Again, assuming 100-percent bioavailability, one egg produced every other day, and the entire 2-day dose being present in that one egg, the egg would contain 0.176 mg. Assuming

the egg weighed 50 grams, the egg would contain 3.5 µg/g of boron. Assuming a daily egg consumption value of 100 grams, then a total dose would be 0.350 mg. For a 60-kg adult female, it would equate to a daily dosage of .0.006 mg/kg body weight, or approximately 22 times less than a TDI of 0.13 mg/kg.

5A.4 Sulfamethoxazole

While quite variable, the highest concentration of sulfamethoxazole detected by Guo et al. was effluent from a WWTP at 1,593 ng/L. Anderson et al. (2000) reported a similar value (1,400 ng/L) in DTRW; nevertheless, the higher WWTP value was used for worst-case scenario calculations.

Steady-state concentrations of sulfamethoxazole were achieved in swine after 48-hours of exposure (Mengelers et al., 2001). Ignoring the half-life of 12 hours, sulfamethoxazole residues in tissues were calculated as those accumulated during the last 48-hour period prior to slaughter. Schwab (2005) calculated a human ADI of 130 µg/kg/day and a $PNEC_{dw}$ of 1,900,000 ng/L. The Australians used an ADI of 10 µg/kg/day and a DWG of 35,000 ng/L. A DWEL of 18,000,000 ng/L was given by Snyder et al. (2008). Notably, the highest concentration detected in wastewater effluent in the Guo et al. (2010) report is almost 22 times lower than the lowest drinking water benchmark of 35,000 ng/L.

A 364-kg steer ingesting 65.9 liters of water per day containing 1,593 ng/L of sulfamethoxazole would ingest a dose of ~105 µg/day or 0.29 µg/kg/day. Assuming the entire steady-state (2-d) dose (105 µg/d x 2 d = 210 µg) was found in 236 kg of muscle tissue, there would be 0.89 µg/kg of muscle tissue or 0.89 ng/g. Assuming a 60-kg adult female ingesting 300 grams of meat per day, the dosage would be 4.5 ng/kg, which is approximately 2,220 times lower than the most conservative ADI of 10 µg/kg/day.

Taking a different approach, an estimated ADI based upon the lowest therapeutic dose was used according to Snyder et al. (2008). The lowest therapeutic dose used was 400 mg/D. For a 60-kg female, the daily dosage would be 6.67 mg/kg. Dividing this dose by a UF of 3,000 gives an estimated ADI of 0.0022 mg/kg/D or 2.2 µg/kg/D, which is more conservative than the ADI of 10 µg/kg/D. With either calculation, the contribution of residue from DTRW is a fraction of the ADI.

Assuming that laying hens (1.6 to 1.9 kg) would consume approximately 0.32 liters per day at the upper end of the consumption range (OMAFRA, 2016) and that a laying hen would produce four eggs per week (FAO, 2003), one can calculate worst-case exposures through egg products. If 0.32 liters of DTRW containing 1.593 µg/L of sulfamethoxazole were provided, then a daily dosage for a 1.9-kg bird would be 0.510 µg total or 0.268 µg/kg body weight ([0.510 µg/L x 0.32] ÷ 1.9 kg = 0.268 µg/kg). Again, assuming 100-percent bioavailability, one egg produced every other day, and the entire 2-day dose being present in that one egg, the egg would contain 1.02 µg of sulfamethoxazole. Assuming the egg weighed 50 grams, the egg would contain 0.02 µg/g of antibiotic. Assuming a daily egg consumption value of 100 grams, then a total human dose would be 2.0 µg or 34 ng/kg body weight for a 60-kg adult female. It is approximately 294 times less than the most conservative ADI of 10 µg/kg body weight.

5A.5 PFAS and PFOS

Perfluoroalkylated compounds (PFAS) are comprised of a large number of fluorinated chemicals, including oligomers and polymers, with high thermal, chemical, and biological inertness. Interestingly, perfluorinated compounds are both hydrophobic and lipophobic and do not accumulate in fatty tissues

like other persistent halogenated compounds. A subset of PFAS are perfluorinated organic surfactants, which include perfluorooctane sulfonate (PFOS) and perflourooctanoic acid (PFOA). The latter is listed in Annex B of the Stockholm Convention on Persistent Organic Pollutants. These compounds have been widely used in industrial and consumer applications, including stain- and water-resistant coatings for fabrics, oil-resistant coating for paper products approved for food contact, firefighting foams, mining and oil well surfactants, floor polishes, and insecticide formulations (EFSA, 2008). Given the degree of use, they have become global pollutants. PFOS has been shown to bioaccumulate in fish with a bioconcentration factor estimated to be 1,000 to 4,000. Drinking water is estimated to contribute <0.5 percent of the total human exposure to PFOS.

A tolerable daily intake for PFOS was determined to be 150 ng/kg/D by the Scientific Panel on Contaminants in the Food Chain (EFSA, 2008). A 90th percentile DTRW concentration was determined to be 90 ng/L (Anderson et al., 2010). The Panel used an absolute, worst-case scenario in estimating tissue residues that might accumulate after of beef animals to DTRW. Although the half-life of PFOS in cattle muscle is approximately 165-days (Lupton et al., 2017), the Panel assumed that 100 percent of the daily PFOS residue was transferred to muscle over a 540-day growing period (approximately 18 months) with no losses. It also assumed a constant water intake of 66 L/d across the entire 540-day production cycle. Under such a scenario, a beef animal would consume a total of 3,208 μg of PFOS, which would be distributed to 236 kg of muscle for a concentration of 13.6 μg/kg. A 60-kg female consuming 300 grams of meat would ingest 68 ng/kg/D of PFOS, which can be compared to the ADI of 150 ng/kg/D, a margin of safety with respect to the ADI of 2. The example with PFOS illustrates the difficulty of achieving ADI values when the concentrations of a chemical compound are at extremely low concentrations in source waters.

Assuming that laying hens (1.6 to 1.9 kg) would consume approximately 0.32 liters per day at the upper end of the consumption range (OMAFRA, 2016) and that a laying hen would produce four eggs per week (FAO, 2003), one can calculate worst-case exposures through egg products. If 0.32 liters of DTRW containing 90 ng/L of PFOS were provided, then a daily dosage for a 1.9-kg bird would be 29 ng and a total dose of 203 ng/week. Again, assuming 100-percent bioavailability, one egg produced every other day, and the entire 1-week dose being present in that one egg, the egg would contain 203 ng of PFOS. Assuming the egg weighed 50 grams, the egg would contain 4.1 ng/g of PFOS. Assuming a daily egg consumption value of 100 grams, then a total human dose would be 406 ng or 6.8 ng/kg body weight for a 60-kg adult female. It is approximately 22 times less than the ADI of 150 ng/kg body weight.

5A.6 Atrazine

Atrazine is a widely used herbicide for the control of weeds in agricultural crops. It belongs to the triazine class of chemicals, which includes simazine, cyanazine, propazine, and ametryn. Guo et al. (2010) reported concentrations of 5 ng/L in surface waters heavily influence by DTRW. There are a number of human health benchmarks for atrazine. Currently, the EPA MCL for atrazine is 0.003 mg/L (3000 ng/L). The California Office of Environmental Health Hazard Assessment (OEHHA) has set a public health goal (PHG) of 0.00015 mg/L (150 ng/L). Detected concentrations are well below the more stringent OEHHA PHG.

The potential for atrazine to accumulate in animal tissues is low; therefore, atrazine concentrations were calculated as those consumed within the 24-hour period prior to slaughter. Using a 5-ng/L concentration estimate, a 364-kg steer ingesting 65.9 liters of water per day would receive a total dose of 330 ng of atrazine. Assuming the entire dose was in 236 kg of muscle, there would be 1.4 ng of atrazine per kg muscle, or 0.42 ng in a 300-g serving of muscle. For a 60-kg human, this exposure would amount to 0.007 ng/kg body weight or about 14,300-fold lower than the AWWA (Anderson et al., 2010; Appendix J) estimated ADI of 0.0001 mg/kg (100 ng/kg).

For laying hens, a total daily dose would be 1.6 ng of atrazine. Assuming that two daily doses would be deposited in a single egg, each egg would contain 3.2 ng of atrazine. A 60-kg human consuming 100 g of eggs would have a total intake of atrazine of 6 ng or approximately 0.1 ng/kg body weight. Under a worst-case scenario, the exposure from egg residues originating in DTRW would be about 940-fold lower than a conservative ADI.

5A.7 Bifenthrin

First registered for use by the EPA in 1985, bifenthrin is an insecticide in the pyrethroid family. Pyrethroids are manmade versions of pyrethrins, which come from chrysanthemum flowers. Bifenthrin is used on various agricultural crops and in homes. Pyrethroids are much less toxic in mammals than they are in insects and fish because mammals have the ability to rapidly break the ester bond in bifenthrin into its inactive acid and alcohol components. In people and rats, bifenthrin is degraded by liver cytochrome P-450. Because it is poorly soluble in water, nearly all bifenthrin will remain in sediments during wastewater treatment; however, it is very harmful to aquatic life. Even in low concentrations, fish and other aquatic animals are affected. Effects on aquatic life would likely drive regulatory limits for the insecticide in water.

Ensminger et al. (2013) measured 20 ng/L bifenthrin concentrations in surface waters of a Sacramento sample set. The Sacramento samples contained greater ($P < 0.0002$) bifenthrin concentrations than were measured at other California sites. Surface water bifenthrin concentrations are likely to be high relative to DTRW because of binding during sedimentation at WWTPs. There is no MCL for bifenthrin, but a chronic ADI of 15,000 ng/kg/D has been suggested by the EPA (1988), and a PNEC of 105,000 ng/L was calculated using methods described by Anderson et al. (2010). Using worst-case calculations, a beef animal consuming 66 L of DTRW containing 20 ng/L would consume 1.32 µg of bifenthrin per day. Assuming all of the bifenthrin was deposited in 236 kg of muscle, the resulting bifenthrin residue would be 5.6 ng/kg. A 60-kg female consuming 300 grams of this muscle per day would ingest 1.7 ng of bifenthrin or 0.028 ng/kg, about 536,000 times lower than the ADI of 15,000 ng/kg/D.

Laying hens (1.9 kg) consuming 0.32 L/d of DTRW containing 20 ng/L of bifenthrin would be exposed to 6.4 ng of bifenthrin per day. Assuming no metabolism or excretion and 2 days of bifenthrin accumulation solely in egg, an egg would contain 12.8 ng of bifenthrin or 0.256 ng/gram of egg, assuming a 50-g egg. A human consuming 100 g of such eggs would be exposed to 25.6 ng of bifenthrin or 0.4 ng/kg of body weight (assuming a 60-kg person). For perspective, a 60-kg person would have to consume approximately 3,500 kg of eggs (in a single day, no less) to supply the ADI (15,000 ng/kg bw) of bifenthrin.

5A.8 Fipronil

First registered for use in the United States in 1996, fipronil is a broad use insecticide that belongs to the phenylpyrazole chemical family. Fipronil is used to control ants, beetles, cockroaches, fleas, ticks, termites, mole crickets, thrips, rootworms, weevils, and other insects. It is used in a wide variety of pesticide products, including granular products for grass, gel baits, spot-on pet care products, liquid termite control products, and products for agriculture. There are more than 50 registered products that contain fipronil.

The EPA uses a chronic RfD for fipronil of 200 ng/kg/D (Federal Register, 2007). A PNEC of 1,400 ng/L was calculated using the methods described by Anderson et al., (2010). Ensminger et al. (2013) measured a mean *maximal* concentration of fipronil in surface waters of California municipalities of 418 ng/L. Using pre-WWTP surface water measurements as a worst-case surrogate for DTRW, exposure estimates were calculated. Using worst-case calculations, a beef animal consuming 66 L of DTRW containing 300 ng/L would consume 19.8 μg of fipronil per day. Assuming all of the fipronil was deposited in 236 kg of muscle, the resulting fipronil residue would be 84 ng/kg. A 60-kg female consuming 300 grams of this muscle per day would ingest 25 ng of fipronil or 0.4 ng/kg, about 500 times lower than the ADI of 200 ng/kg/D.

Assuming a maximal intake of water by laying hens (0.32 L), no metabolism, and 100 percent of the ingested residue directed to the egg during a 2-day period, an egg would contain 192 ng or 3.8 ng fipronil/gram of egg. A 60-kg individual consuming 100 g of eggs would consume 384 ng of fipronil; however, the ADI is 200 ng/kg of body weight, so a 60-kg person would be "allowed" a total consumption of 12,000 ng/d. Assuming a worst-case scenario, the fipronil contribution of daily egg consumption would be approximately 31 times less than the allowable limit (12,000 ng/d ÷ 384 ng/d = 31.3). To illustrate the conservative nature of the Panel's calculation, the EFSA (2006) has reported that 25 to 50 percent of fipronil is excreted in feces; further, tissue residues in hens were primarily (95 percent) metabolites. Residues in tissues (including eggs) were strictly related to dose (EFSA, 2006), indicating that at low exposure levels, fipronil residues would be correspondingly low.

5A.9 Carbaryl

Carbaryl is a man-made cholinesterase inhibiting insecticide. It is commonly used to control aphids, fire ants, fleas, ticks, spiders, and many other outdoor pests (Bond et al., 2016). It is also used in some orchards to thin blossoms on fruit trees. Carbaryl has been registered for use in pesticide products since 1959. No carbaryl products are currently registered for use inside homes or on pets. There are more than 190 registered pesticide products that contain carbaryl. These include sprays, dusts, granules, and water-soluble packages. Many of these products can be used on agricultural crops, home gardens, lawns, and other ornamental plants. Others are used around the outside of homes and on anthills.

The human ADI for carbaryl is 100,000 ng/kg/D (EPA, 2007). The mean concentration of untreated surface water in California was 22 ng/L (CDPR, 2017). Untreated surface water concentrations of carbaryl were used as surrogate for DTRW for the purposes of calculation. Because carbaryl is not bioaccumulative in animals, residues in tissues were calculated as those consumed within the 24-hour period prior to slaughter. A beef animal consuming 66 L of water per day would consume a total of 1.5 μg of carbaryl. Assuming 100-percent distribution to skeletal muscle (236 kg), the concentration of

carbaryl in meat would be 6.2 ng/g. A person consuming 300 grams of meat per day would ingest a dose of carbaryl of 0.03 ng/kg/D, which can be compared to the ADI of 100,000 ng/kg/D. For a 60-kg person to achieve a daily ADI of carbaryl, they would need to consume approximately 16,100 kg (17.8 tons) of beef. Assuming a maximal intake of water by laying hens (0.32 L), no metabolism, and 100 percent of the ingested residue directed to the egg during a 2-day period, an egg would contain 14 ng or 0.3 ng of carbaryl/gram. An individual consuming 100 g of eggs would consume 30 ng of carbaryl. Because the ADI of carbaryl is 100,000 ng/kg body weight, a 60-kg person would not come close to meeting even 0.001 percent of the ADI for carbaryl through egg consumption.

5A.10 Diuron

Diuron is a substituted urea herbicide used to control a wide variety of annual and perennial broadleaf and grassy weeds (Extoxnet, n.d.). It is used to control weeds and mosses on non-crop areas and among many agricultural crops, such as fruit, cotton, sugar cane, and legumes. Diuron works by inhibiting photosynthesis. Diuron has a low acute toxicity to mammals, with a rat oral LD_{50} (or, lethal dose in 50 percent of the test animals) ranging from 1,017 mg/kg to 3,750 mg/kg. Some signs of central nervous system depression have been noted at high levels of diuron exposure. For people, the only reported case of acute oral exposure to the herbicide produced no significant symptoms or toxicity. Cows fed very low doses of dietary diuron had small amounts of residues in whole milk. Cattle fed small amounts accumulated low levels of diuron in fat and muscle, liver, and kidneys. Little tissue storage under field conditions is anticipated.

An ADI for diuron is 3,000 ng/kg/D (Anderson et al., 2010). The *maximum* concentration of diuron measured in wastewater treatment plant effluent into the Santa Ana River (Orange County, California) was 136 ng/L (Guo et al., 2010). Using the maximum concentration of diuron exiting a WWTP as a surrogate for DTRW and an ADI of 3,000 ng/kg/d, a worst-case residue estimate was constructed. Assuming a water consumption of 66 L/d, a 364-kg beef animal would consume 9.0 μg/d. If 100-percent of the diuron was distributed to the animal's 236 kg of skeletal muscle, with no metabolism, the muscle would contain 38 ng/kg. If a 60-kg person consumed 300 grams of meat per day, they would ingest 11 ng of diuron, or 0.19 ng/kg/D. This intake is approximately 15,800 times lower than the ADI of 3,000 ng/kg/D.

For chickens, there would be 1.74 ng/g of egg. Assuming a maximal intake of water by laying hens (0.32 L), no metabolism, and 100 percent of the ingested residue directed to the egg during a 2-day period, an egg would contain 87 ng or 1.7 ng of diruon/gram. An individual consuming 100 g of eggs would consume 174 ng of carbaryl. Because the ADI of diruon is 3,000 ng/kg body weight, a 60-kg person would have to eat 103 kg (227 lbs) of eggs in a day to consume an ADI of carbaryl. Stated another way, to reach the ADI for diuron, an individual would have to ingest approximately 2,070 eggs per day.

5A.11 Ciprofloxicin

Ciprofloxicin is a widely used human label flouroquinoline antibiotic that is also used in veterinary medicine. In human medicine, there are a number of indications for its use in treating infections. The recommended oral dose range in people is 500 to 750 mg every 12 hours (1,000 to 1,500 mg/day) for up to 60 days (for treating post-exposure inhalational anthrax). Long-term carcinogenicity studies in rats and mice resulted in no carcinogenic or tumorigenic effects due to ciprofloxacin at daily oral dose levels

up to 250 and 750 mg/kg to rats and mice, respectively (approximately 1.7- and 2.5- times the highest recommended therapeutic dose based upon mg/m^2) (Herbold et al., 2001).

Adopting the final decision tree for determining a conservative ADI (or comparison value) for new and emerging contaminants recommended by Anderson et al. (2010), the daily therapeutic dosage is divided by 3,000. Assuming a 60-kg female, the lowest dosage of ciprofloxacin would be 1,000 mg ÷ 60 kg = 16.7 mg/kg/day. The estimated ADI would be 6 µg/kg/D (16.7 mg/kg/D ÷ 3,000 = 0.006 mg/kg/day). The 90th percentile DTRW concentration is reported by Anderson et al. (2010) as 100 ng/L.

Because ciprofloxacin is not bioaccumulative in animals, residues in tissues were calculated as those consumed within the 24-hour period prior to slaughter. Assuming a water consumption of 66 L/d, a 364-kg beef animal would consume 6.6 µg/d of ciprofloxacin. If 100 percent of the antibiotic was distributed to the animal's 236 kg of skeletal muscle, with no metabolism, the muscle would contain 28 ng/kg. If a 60-kg person consumed 300 grams of meat per day, they would ingest 8 ng of ciprofloxacin, or 0.14 ng/kg/D. This intake is approximately 43,000 times lower than the ADI of 6,000 ng/kg/D.

Eggs from a laying hen would contain 1.28 ng ciprofloxacin per gram of egg. Assuming a maximal intake of water by laying hens (0.32 L), no metabolism, and 100 percent of the ingested residue directed to the egg during a 2-day period, a 50-g egg would contain 64 ng or 1.3 ng of ciprofloxacin/gram. An individual eating 100 g of eggs would consume 130 ng of ciprofloxacin. Because the ADI of ciprofloxacin is 6,000 ng/kg body weight, a 60-kg person would have to eat 277 kg (609 lbs) of eggs in a day to consume an ADI of ciprofloxacin.

5A.12 Diclofenac

Diclofenac [2-(2,6-dichloroanilino)phenylacetic acid] is a non-specific inhibitor of cyclooxygenase (COX 1 and COX 2). By inhibiting COX 2 enzymes, it reduces the production of prostaglandins associated with pain, fever, and inflammation. It is sold under a variety of tradenames, primarily as the sodium or potassium salt. In some countries, it is sold as an over-the-counter drug for minor aches, pains, and fever associated with common infections. In the United States, diclofenac is FDA-approved for use in horses for the control of joint pain and inflammation. It is well tolerated at recommended doses (Plumb, 2015). Due to the intoxication of scavenging birds feeding on carcasses from diclofenac-treated animals, it has been banned for veterinary use in many countries.

The drug has been used in human medicine for many years for the long-term symptomatic treatment of rheumatoid arthritis, osteoarthritis, ankylosing spondylitis, and primary nocturnal enuresis. The daily dose varies between 50 and 150 mg/D, depending on the route of administration and on the disease to be treated, and can be used for up to 12 weeks. A maximum daily dose of 125 mg for the treatment of ankylosing spondylitis was selected for the ADI calculation (Snyder et al. [2008] used 100 mg as the lowest daily dose). Although no carcinogenicity studies are available for diclofenac, such studies are not believed to be necessary given a lack of demonstrated genotoxicity (EMEA, 2003).

If the highest therapeutic dose is divided by 3,000, a conservative ADI for a 60-kg female would be 0.7 µg/kg/D (125 mg daily dose ÷ 60 kg = 2.08 mg/kg ÷ 3,000 = 0.7 µg/kg/D). A 90th percentile concentration in DTRW is 230 ng/L (Anderson et al., 2010).

Because diclofenac is not bioaccumulative in animals, residues in tissues were calculated as those consumed within the 24-hour period prior to slaughter. Assuming a DTRW consumption of 66 L/d, a 364-kg beef animal would consume 15.2 μg/d of diclofenac. If 100 percent of the drug was distributed to the animal's 236 kg of skeletal muscle, with no metabolism, the muscle would contain 64 ng/kg. If a 60-kg person consumed 300 grams of meat per day, he would ingest 19 ng of ciprofloxacin, or 0.32 ng/kg/D. This intake is approximately 2,200 times lower than the ADI of 700 ng/kg/D.

Assuming a maximal intake of water by laying hens (0.32 L), no metabolism, and 100 percent of the ingested residue directed to the egg during a 2-day period, a 50-g egg would contain 147 ng or 2.9 ng of diclofenac/gram. A 60-kg individual eating 100 g of eggs per day would consume 290 ng of ciprofloxacin. Because the ADI of ciprofloxacin is 700 ng/kg body weight, a 60-kg individual has a total ADI of 42,000 ng per day, about 145 times the amount provided by a meal of eggs.

5A.13 Ketoprofen

Ketoprofen [2-(3-benzylphenyl)-proprionic acid] is a widely used non-steroidal anti-inflammatory used in human and veterinary medicine with similar indications to diclofenac. In people, a maximum dose of the immediate release formulation is 300 mg/D; for the extended release formulation, it is 200 mg/D. The common dose for rheumatoid arthritis is 50 mg given four times per day for a total daily dose of 200 mg. It is not genotoxic or carcinogenic (EMSA, 1995).

A toxicological NOEL of 2 mg/kg derived from a teratogenicity study in rabbits led to an ADI of 0.020 mg/kg/D (UF of 100) (EMSA, 1995). This can be compared to the conservative ADI using the method of Snyder et al. (2008) of 0.0011 mg/kg/D (200 mg daily dose = 3.33 mg/kg for 60-kg female ÷ 3000 = 0.0011 mg/kg/D or 1100 ng/kg/D). A 90th percentile DTRW concentration is 43 ng/L (Anderson et al., 2010).

Because ketoprofen is not bioaccumulative in animals, residues in tissues were calculated as those consumed within the 24-hour period prior to slaughter. Assuming a DTRW consumption of 66 L/d, a 364-kg beef animal would consume 2.8 μg/d of ketoprofen. If 100 percent of the drug was distributed to the animal's 236 kg of skeletal muscle, with no metabolism, muscle would contain 12 ng/kg. For a 60-kg person eating 300 grams of meat per day, the ketoprofen dosage would be 0.06 ng/kg/D (compared to estimated ADI of 1100 ng/kg/D), or approximately 18,300 times lower than the ADI.

Assuming a maximal intake of water by laying hens (0.32 L), no metabolism, and 100 percent of the ingested residue directed to the egg during a 2-day period, the concentration in eggs would be 0.55 ng/g egg. Consumption of 100 g of egg per day would result in a dose of 55.5 ng or 0.93 ng/kg for a 60-kg person (compared to the ADI of 1100 ng/kg/D). Expressed another way, an individual would have to consume 12 kg of eggs per day to meet the ADI.

5A.14 Erythromycin

Erythromycin is a macrolide antibiotic that is bactericidal. It is used to treat and prevent a variety of infections. It is available in a variety of formulations including delayed release capsules, liquid, tablet, delayed release tablet, and coated tablet. It is labeled for use in cattle for treating respiratory disease, and it is sometimes used in other species including dogs, cats, ferrets, horses (foals), and birds (all extra-

label use). A low human therapeutic dose is 250 mg given three times per day for a total daily dose of 750 mg.

Using the methodology of Snyder et al. (2008), a minimum therapeutic dose for a 60-kg female would be 12.5 mg/kg/D. Using their uncertainty factor of 3,000 would translate into a conservative ADI (or comparison value) of 0.0042 mg/kg/D or 4,200 ng/kg/D. A 90th percentile DTWR concentration is 113 ng/L (Anderson et al., 2010).

Assuming a DTRW consumption of 66 L/d, a 364-kg beef animal would consume 7.5 μg/d of erythromycin. If 100 percent of the drug was distributed to the animal's 236 kg of skeletal muscle, with no metabolism, the muscle would contain 32 ng/kg. A 60-kg person eating 300 grams of meat per day would consume a total of 9 ng of erythromycin or, on a body weight basis, 0.158 ng/kg. With respect to the ADI, the daily erythromycin intake from beef provided DTRW as its only water source would be approximately 26,600 times less than "acceptable."

Assuming a maximal intake of water by laying hens (0.32 L), no metabolism, and 100 percent of the ingested residue directed to the egg during a 2-day period, the total erythromycin content of an egg would be 72 ng or 1.45 ng/g for a 50-g egg. A 60-kg human who consumed 100 g of egg per day would receive approximately 2.4 ng of erythromycin per kg body weight, a dose well below the estimated ADI of 4,200 ng/kg/D.

5A.15 PFOA

See **Section 5A.5** for background on PFOA. In dietary items, PFOA concentrations are generally lower than those for PFOS. PFOA can bioaccumulate in fish, but to a lesser extent than PFOS. In cattle, PFOA is cleared completely in 9 days with a plasma half-life of 19 ± 3 h (Lupton et al., 2017). It is estimated that non-food, such as household dust, source exposure to PFOA could be as high as 50 percent. Drinking water is estimated to contribute <16 percent of total exposure. A TDI for PFOA has been determined to be 1.5 μg/kg/D (1,500 ng/kg/D) (EFSA, 2008).

A 90th percentile water concentration reported by Anderson et al. (2010) was 28 ng/L. The Panel used an absolute, worst-case scenario in estimating tissue residues that might accumulate after of beef animal exposures to DTRW. Although the half-life of PFOA in cattle muscle is less than 1 day (Lupton et al., 2017), the Panel assumed that 100 percent of the daily PFOA residue was transferred to muscle during the last 7 days prior to slaughter with no losses through urine or feces. The Panel also assumed a constant water intake of 66 L/d during the 7-day period prior to slaughter. Under such a scenario, a beef animal would consume a total of 12.9 μg of PFOA, which would be distributed to 236 kg of muscle for a concentration of 0.055 μg/kg. A 60-kg person consuming 300 grams of meat would ingest 0.27 ng/kg/D of PFOA, which can be compared to the ADI of 1,500 ng/kg/D, a margin of safety with respect to the ADI of nearly 5,500.

Assuming that laying hens (1.6 to 1.9 kg) would consume 0.32 liters per day and that a laying hen would produce four eggs per week (FAO, 2003), one can calculate worst-case exposures through egg products. If 0.32 liters of DTRW containing 28 ng/L of PFOA were provided, then a daily dosage for a 1.9-kg bird would be 9 ng and a total dose of 63 ng/week. Again, assuming 100-percent bioavailability, one egg produced every other day, and the entire 1-week dose being present in that one egg, the egg would

contain 63 ng of PFOS. Assuming the egg weighed 50 grams, the egg would contain 1.25 ng/g of PFOS. Assuming a daily egg consumption value of 100 grams per day, then a total human dose would be 125 ng or 2.1 ng/kg body weight for a 60-kg adult. It is approximately 720 times less than the ADI of 1,500 ng/kg body wt.

5A.16 Bisphenol-A

Bisphenol A (BPA) is a chemical produced in large quantities for use primarily in the production of polycarbonate plastics and epoxy resins (NIEHS, 2010). Polycarbonate plastics have many applications including use in some food and drink packaging (e.g., water and infant bottles, compact discs, impact-resistant safety equipment, and medical devices). Epoxy resins are used as lacquers to coat metal products such as food cans, bottle tops, and water supply pipes. Some dental sealants and composites may also contribute to BPA exposure. The primary source of exposure to BPA for most people is through the diet. While air, dust, and water are other possible sources of exposure, BPA in food and beverages accounts for the majority of daily human exposure. BPA can leach into food from the protective internal epoxy resin coatings of canned foods and from consumer products such as polycarbonate tableware, food storage containers, water bottles, and baby bottles. BPA can also be found in breast milk.

One reason people may be concerned about BPA is because human exposure to BPA is widespread. The 2003-2004 National Health and Nutrition Examination Survey (NHANES III) conducted by the CDC found detectable levels of BPA in 93 percent of 2,517 urine samples from people ages 6 years and older. The CDC NHANES data are considered representative of exposures in the United States. Another reason for concern, especially for parents, may be because some animal studies report effects in fetuses and newborns exposed to BPA.

EFSA (2015) published its comprehensive re-evaluation of BPA exposure and toxicity in January 2015 when it reduced the TDI for BPA from 50 to 4 µg/kg/D. The TDI was made temporary, and EFSA committed to re-evaluate BPA toxicity again when a 2-year study by the US National Toxicology Program becomes available in 2017. A TDI for BPA was determined to be 0.05 mg/kg/D in Korea (Choi et al., 2010).

The 90th percentile concentration in tertiary treated water was 286 ng/L (Anderson et al., 2010). Assuming a DTRW consumption of 66 L/d, a 364-kg beef animal would consume 18.9 µg/d of BPA. If 100 percent of the plasticizer was distributed to the animal's 236-kg of skeletal muscle, with no metabolism, the muscle would contain 80 ng/kg. A 60-kg female consuming 300 grams of meat per day would ingest a dose of 0.4 ng/kg/D, which can be compared to the EFSA recommended TDI of 4,000 ng/kg/D for a 10,000-fold difference.

Assuming a maximal intake of water by laying hens (0.32 L), no metabolism, and 100 percent of the ingested residue directed to the egg during a 2-day period, the total BPA content of an egg would be 183 ng or 3.66 ng/g for a 50-g egg. A 60-kg human who consumed 100 g of egg per day would receive approximately 366 ng of BPA total or 6.1 ng/kg per kg body weight per day, a nearly 660-fold difference from the TDI of 4,000 ng/kg/D. To reach the TDI of 4,000 ng/kg/D, an individual would have to ingest approximately 1,300 eggs per day.

5A.17 TCEP

Tris (2-chloroethyl) phosphate is currently used as a flame-retardant in furniture containing polyurethane foam, as well as in electronics, textiles, and carpet. It has been listed on California's list of carcinogens since 1992, and New York has recently banned its use in products intended for children under 3 years of age because of evidence of adverse health effects.

Global production of flame retardants has risen to estimates of above 1-million metric tons per year with phosphate ester flame retardant compounds comprising approximately 20 percent of the total. More specifically, the production of TCEP has risen in the past several decades to between 500,000 to 1,000,000 pounds per year, which is a large increase from the estimated 1-metric ton of TCEP produced in 1975.

No *in vivo* human data for absorption, distribution, metabolism, or elimination of TCEP by any route of exposure is available, although there are some limited *in vitro* data on metabolism in liver slices or via microsomes. Oral dosing studies in rats and mice indicate that TCEP is well absorbed following gavage, which is the administration of food or drugs through a tube leading down the throat to the stomach. Distribution studies via oral and intravenous routes show wide and rapid distribution throughout the body, but no accumulation in tissue; however, tissue-to-blood ratios were highest in the liver and kidneys. In rodents, urine is the main route of excretion for TCEP, following oral and IV administration, with minimal excretion in exhaled air and feces. Elimination from blood is biphasic. The maximum average concentration in tissues occurs by 6 hours post-exposure, with adipose tissue having the longest tissue elimination half-life of 87 hours.

TCEP has been detected in outdoor and indoor air, surface water, groundwater, house dust, food, and consumer products. The primary sources of exposure to TCEP for consumers appear to be dust and indoor air. For toddlers and infants, the mouthing of foam is a significant exposure route. The upper-bound estimate of daily intake from dust was 0.2 µg/kg/day for infants and 0.3 µg/kg/day for children ages 6-months to 4-years old.

For chronic exposures, the most sensitive endpoint is focal hyperplasia of renal tubular epithelium in female rats exposed via gavage for 2 years. The Agency for Toxic Substances and Disease Registry (ATSDR) estimated a $BMDL_{10}$ is 23.4 mg/kg/day based upon this information (ATSDR, 2012). Both sexes developed renal tubular tumors, suggesting that the renal hyperplasia was a preneoplastic lesion. The most sensitive non-cancer effect that is clearly not preneoplastic was degenerative lesions in the brain of female rats. Based on the ATSDR analysis, the $BMDL_{10}$ for this endpoint is 42.8 mg/kg/day. An alternative benchmark, based upon a well conducted rodent study, determined a NOAEL of 125 mg/kg/day.

TCEP concentrations detected in DTRW range from a low of 240 µg/L to 730 µg/L with a 90th percentile concentration of 688 µg/L (Anderson et al., 2010). Using the 688 ng/L concentration, a 364 kg (800 lb) steer ingesting 66 L of water per day would ingest a daily dose of TCEP of 45,339 ng (65.9 L x 688 ng/L) or a daily dosage of 124.6 ng/kg, which is well below available benchmarks. Assuming 100-percent bioavailability and 100 percent of the dose accumulates in muscle tissue, there would be 192.1 ng per kg of muscle (45,339 ng ÷ 236 kg muscle) or 192 ng/gram of muscle. Using a daily food consumption value for a muscle of 300 grams, the daily dose of TCEP would be 57.6 ng or for a 60-kg person, equivalent to

0.96 ng/kg body weight (57.6 ng ÷ 60 kg). The most sensitive benchmark (TDI, ADI, or RfD) for TCEP was proposed by Schriks et al. (2010) at 22 µg/kg/day. The worst-case intake of TCEP estimated by the panel is about 22,900 times lower than the benchmark acceptable intake.

Making similar calculations for poultry assumes laying hens (1.6 to 1.9 kg) would consume approximately 0.32 L per day at the upper end of the consumption range (OMAFRA, 2016). While individual egg production varies depending on a number of factors, the FAO (2003) estimates that a laying hen would produce four eggs per week. If 0.32 liters of water containing 688 ng/L was provided, then a daily dose for a 1.9-kg bird would be 220 ng. Again, assuming 100-percent bioavailability, one egg produced every other day, and the entire 2-day dose being present in one egg, the egg would contain 440 ng. Assuming the egg weighed 50 grams, the egg would contain 8.8 ng/g TCEP. Assuming a daily egg consumption value of 100 grams per day, then a total dose 880 ng. For a 60-kg adult, the TCEP exposure would equate to a daily dosage of 14.7 ng/kg body weight, which is about 1,500 times the most sensitive benchmark of 22 µg/kg/day.

5A.18 Arsenic

Arsenic is ubiquitous in nature and commonly found in drinking water sources in California. The chronic intake of inorganic arsenic can lead to a variety of adverse effects, including skin lesions, peripheral neuropathy, gastrointestinal symptoms, diabetes, renal system effects, cardiovascular disease, and cancer. Organic arsenic compounds, which are abundant in seafood, are less harmful. Exposure to inorganic arsenic occurs mainly through the consumption of groundwater containing naturally high levels of inorganic arsenic, food prepared with this water, and food crops irrigated with high-arsenic water sources.

A 10-µg/L federal MCL for arsenic has been in effect since January 2006. California's revised arsenic MCL of 10 µg/L became effective in November 2008. California has a PHG of 0.004 µg/L based on a lung and urinary bladder cancer risk, corresponding to a *de minimis* cancer risk level (i.e., up to one excess case of cancer per million people per 70-year lifetime, if the drinking water contained arsenic at the concentration of the PHG).

The State Water Board's Groundwater Ambient Monitoring and Assessment (GAMA) Program, in its Groundwater Information Sheet for Arsenic (State Water Board, 2016), has a map of arsenic detection, based on monitoring information from the State Water Board's water quality monitoring database. As of August 2016, 947 drinking water wells reported concentrations greater than 10 µg/L (of 12,237 wells sampled). The statewide average concentration of arsenic in groundwater is 9.8 µg/L (Helperin et al., 2001). The highest concentration of arsenic detected in groundwater in California was determined to be 650 µg/L in a well in Sonoma County.

The EPA, National Academy of Science (NAS), and Canadian safe upper concentrations of arsenic in water for livestock are 200 µg /L, 200 µg /L, and 500 µg /L, respectively (Morgan, 2011).

In a review of the latest scientific evidence conducted in 2010, the Joint Food and Agriculture Organization of the United Nations (FAO)/WHO Expert Committee on Food Additives (JECFA) determined that the lower limit on the benchmark dose for a 0.5-percent increased incidence of lung

cancer (BMDL0.5) from epidemiological data to be 3.0 µg/kg body weight per day. When concentrations in water are below the WHO drinking water guideline value, human health effects are unlikely.

DTRW that is intended for potable reuse must meet all federal and state drinking water guidelines; therefore, the arsenic MCL of 10 µg /L is 20 times lower than the EPA and NAS livestock benchmark of 200 µg /L and would not be expected to cause an adverse health effect.

Assuming an average of 10-µg /L arsenic concentration, a 364-kg 800-lb steer consuming 66 L of water per day would ingest a daily dose of arsenic of 660 µg. Assuming all of the ingested arsenic is found in muscle, each gram of muscle would contain 2.8 ng of arsenic. The ingestion of 300 grams of muscle per day would equal a daily dose of 0.84 µg or 0.014 µg/kg of arsenic for a 60-kg person, which is approximately 215 times lower than the $BMDL_{0.5}$ of 3 µg/kg body weight per day.

For laying hens consuming 0.32 L of DTRW containing 10 µg/L per day, a daily dose would be 3.2 µg. If a 2-day dose was found in one egg, there would be 6.4 µg in a 50-gram egg. Assuming a daily consumption of 100 grams of egg per day, the daily dose would be 12.8 µg or a daily dosage of 0.2 µg/kg for a 60-kg female, which is 15 times lower than the $BMDL_{0.5}$ of 3 µg/kg body weight per day.

5A.19 N-Nitrosodimethylamine (NDMA)

N-Nitrosodimethylamine potentially occurs in DTRW when source water contains nitrogenous precursor chemicals such as dimethylamine and is treated with chloramine. NDMA is the predominant nitrosamine found in treated wastewaters.

NDMA causes cancer in laboratory animals such as rats and mice. NDMA is identified as a carcinogen under California's Health and Safety Code (Proposition 65). In addition, the EPA identifies NDMA as a “probable human carcinogen” and the National Toxicology Program lists NDMA as "reasonably anticipated to be a human carcinogen." Exposure to high levels of NDMA may cause liver damage in people. NDMA is not believed to be bioaccumulative.

NDMA is detected in treated water at parts per trillion concentrations. California has established a public health goal of 3 ng/L in drinking water, based on a 1 in 10^{-6} lifetime excess cancer risk (https://www.epa.gov/sites/production/files/201403/documents/ffrrofactsheet_contaminant_ndma_january2014_final.pdf). In addition, California has established a notification level of 10 ng/L, which is a health-based advisory level for chemicals in drinking water that lack a MCL. Massachusetts has established a regulatory limit of 1 x 10^{-5} mg/L in drinking water. NDMA has an ADI or RfD of 0.008 µg/kg/day (Anderson et al., 2010)

Using the notification level of 10 ng/L concentration as an upper limit of what the concentration would be in DTRW, a 364 kg beef animal consuming 66 L of water per day would ingest 660 ng of NDMA per day. If 100% of the ingested dose was distributed to the animal’s 236 kg of skeletal muscle, with no metabolism, the muscle would contain 2.8 ng/kg. A 60 kg female consuming 300 grams of meat per day would ingest a dose of 0.84 ng or a dosage of 0.014 ng/kg/day (0.000014 µg/kg/day). This would be approximately 571-fold lower than the ADI of 0.0008 µg/kg/day.

Assuming a maximal daily intake of water by laying hens of 0.32 L with 100% of the ingested parent residue incorporated into a 50-gram egg during a 2-day period (6.4 ng) the concentration would be

0.128 ng/g of egg. A 60 kg human ingesting 100 grams of egg per day would be exposed to a total dose of 12.8 ng or a dosage of 0.213 ng/kg/day (0.000213 µg/kg/day). This would be approximately 3.76-fold lower than the ADI.

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APPENDIX 5B: MCLs FOR CHEMICALS FROM THE NPDWR

Table 5B-1: National Primary Drinking Water Regulation (NPDWR) Chemicals and Associated Maximum Contaminant Levels (EPA, 2017)

Contaminant	Class	MCL (ng/L)
Acrylamide	Organic	a
Alachlor	Organic herbicide	2,000
Alpha/photon emitter	Radiation	15 pCi/L
Antimony	Inorganic element	6,000
Arsenic	Inorganic element	10,000
Asbestos (fibers >10 µm)	Inorganic chemical	$7x10^6$ fibers/L
Atrazine	Organic herbicide	3,000
Barium	Inorganic element	$2x10^6$
Benzene	Organic solvent	5,000
Benzo(a)pyrene	Organic PAH [b]	200
Beryllium	Inorganic element	4,000
Beta photon emitter	Radiation	4 mRem/yr
Bromate	Inorganic water disinfection product	10,000
Cadmium	Inorganic element	5,000
Carbofuran	Organic insecticide	40,000
Carbon tetrachloride	Organic solvent	5,000
Chloramines (as Cl_2)	Disinfectant	$4x10^6$
Chlordane	Organic insecticide	2,000
Chlorine (as Cl_2)	Disinfectant	$4x10^6$
Chlorine dioxide	Disinfectant	$8x10^5$
Chlorite	Inorganic water disinfection product	$1x10^6$
Chlorobenzene	Organic solvent	$1x10^5$
Chromium (total)	Inorganic element	$1x10^5$
Copper	Inorganic element	$1.3x10^6$
Cyanide (free)	Inorganic industrial chemical	$2x10^5$
2,4-D	Organic herbicide	70,000
Dalapon	Organic herbicide	$2x10^5$
1,2-Dibromo-3-chloropropane (DBCP)	Organic pesticide	200
o-Dichlorobenzene	Organic solvent	$6x10^5$

a Specific water treatment requirements are enforced when used during water disinfection.
b Polyaromatic hydrocarbon.
Note: Data are expressed in nanogram per liter (ng/L) rather than microgram per liter (mg/L) to facilitate comparisons with other tables in this Panel report.

Table 5B-1 (cont): National Primary Drinking Water Regulation (NPDWR) Chemicals and Associated Maximum Contaminant Levels (EPA, 2017)

Contaminant	Class	MCL (ng/L)
p-Dichlorobenzene	Organic solvent	75,000
1,2-Dichloroethane	Organic solvent	5,000
1,1-Dichloroethylene	Organic reagent	7,000
cis-1,2-Dichloroethylene	Organic reagent	70,000
trans-1,2-Dichloroethylene	Organic reagent	$1x10^5$
Dichloromethane	Organic solvent	5,000
1,2-Dichloropropane	Organic solvent	5,000
Di(2-ethylhexyl) adipate	Organic industrial intermediate	$4x10^5$
Di(2-3thylhexyl) phthalate	Organic industrial intermediate	6,000
Dinoseb	Organic herbicide	7,000
Dioxin (2,3,7,8-TCDD)	Organic product of combustion	0.03
Diquat	Organic herbicide	20,000
Endothall	Organic herbicide	$1x10^5$
Endrin	Organic pesticide	2,000
Epichlorohydrin	Organic	a
Ethylbenzene	Organic industrial intermediate	$7x10^5$
Ethylene dibromide	Organic pesticide	50
Fluoride	Inorganic element	$4x10^6$
Glyphosate	Organic herbicide	$7x10^5$
Haloacetic acids	Organic water disinfection product	60,000
Heptachlor	Organic insecticide	400
Heptachlor epoxide	Organic insecticide degradant	200
Hexachlorobenzene	Organic fungicide	1,000
Hexachlorocyclopentadiene	Organic industrial intermediate	50,000
Lead	Inorganic element	15,000
Lindane	Organic insecticide	200
Mercury (inorganic)	Inorganic element	2,000
Methoxychlor	Organic insecticide	40,000
Nitrate (measured as nitrogen)	Inorganic fertilizer	$10x10^6$
Nitrite (measured s nitrogen)	Inorganic fertilizer	$1x10^6$
Oxamyl (Vydate)	Organic pesticide	$2x10^5$
Pentachlorophenol	Organic pesticide	1,000
Picloram	Organic herbicide	$5x10^5$
Polychlorinated Biphenyls (PCBs)	Organic industrial insulators	500
Radium (226 and 228 isotopes)	Radioactive inorganic element	5 pCi/L
Selenium	Inorganic element	50,000

a Specific water treatment requirements are enforced when used during water disinfection.
b Polyaromatic hydrocarbon.
Note: Data are expressed in nanogram per liter (ng/L) rather than microgram per liter (mg/L) to facilitate comparisons with other tables in this Panel report.

Table 5B-1 (cont): National Primary Drinking Water Regulation (NPDWR) Chemicals and Associated Maximum Contaminant Levels (EPA, 2017)

Contaminant	Class	MCL (ng/L)
Simazine	Organic herbicide	4,000
Styrene	Organic industrial intermediate	$1x10^5$
Tetrachloroethylene	Organic solvent	5,000
Thallium	Inorganic element	2,000
Toluene	Organic solvent	$1x10^6$
Total trihalomethanes	Organic water disinfection product	80,000
Toxaphene	Organic insecticide	3,000
2,4,5-TP (Silvex)	Organic herbicide	50,000
1,2,4-Trichlorobenzene	Organic industrial intermediate	70,000
1,1,1-Trichloroethane	Organic solvent	$2x10^5$
1,1,2-Trichloroethane	Organic solvent	5,000
Trichloroethylene	Organic solvent	5,000
Uranium	Radioactive inorganic element	30,000
Vinyl chloride	Organic industrial intermediate	2,000
Xylenes (total)	Organic solvent	$10x10^6$

[a] Specific water treatment requirements are enforced when used during water disinfection.
[b] Polyaromatic hydrocarbon.
Note: Data are expressed in nanogram per liter (ng/L) rather than microgram per liter (mg/L) to facilitate comparisons with other tables in this Panel report.

References

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APPENDIX 5C: CHEMICALS OF POTENTIAL HUMAN HEALTH CONCERN FROM CCL 3 AND CCL 4

Three pesticides (i.e., disulfoton, fenamiphos, and molinate) that are no longer in production and are not expected to be detected in public waters (EPA, 2017b) were removed from CCL 3. Other chemicals were removed from CCL 3 because regulatory action occurred during the assessment of CCL 3. For example, a positive regulatory determination[38] was made for strontium, and it has been added to the NPDWR. Meanwhile, a negative regulatory determination was declared for 1,3-dinitrobenzene, dimethoate, terbufos, and terbufos sulfone; therefore, they are not included in the NPDWR and have been purged from CCL 4. Perchlorate was not included in the CCL 4 because a positive regulatory determination was made in 2011. Finally, two chemicals were added to CCL 4: manganese and nonylphenol.

38 A regulatory determination is a formal decision on whether the US EPA should develop a national primary drinking water regulation for contaminant. The Safe Drinking Water Act requires the agency to make regulatory determinations for at least five contaminants from the most recent CCL within five years after the completion of the previous round of regulatory determinations. A list of regulatory determinations for the previous CCLs is available at http://www2.epa.gov/ccl.

Table 5C-I: Chemicals of Potential Human Health Concern Included in the Third (2009) and Fourth (2016) Contaminant Candidate List of the Environmental Protection Agency (EPA CCL 3, 2009 and CCL 4, 2016)

CCL 3, 2009	CCL 4, 2016	Use/Occurrence
1,1-Dichloroethane	1,1-Dichloroethane	Solvent/Chemical Intermediate
1,1,1,2-Tetrachloroethane	1,1,1,2-Tetrachloroethane	Solvent/Chemical Intermediate
1,2,3-Trichloropropane	1,2,3-Trichloropropane	Solvent/Chemical Intermediate
1,3-Butadiene	1,3-Butadiene	Chemical Intermediate
1,3-dinitrobenzene	Removed at CCL 3 RD[a]	Chemical Intermediate
1,4-Dioxane	1,4-Dioxane	Solvent
17-α-estradiol	17-a-estradiol	Pharmaceutical/Hormone
17-β-estradiol	17-β-estradiol	Pharmaceutical/Hormone
1-Butanol	1-Butanol	Solvent/Excipient
2-Methoxyethanol	2-Methoxyethanol	Consumer Care Product
2-Propen-1-ol	2-Propen-1-ol	Chemical Intermediate
3-Hydroxycarbofuran	3-Hydroxycarbofuran	Pesticide degradant
4,4'-Methylenedianiline	4,4'-Methylenedianiline	Chemical Intermediate
Acephate	Acephate	Insecticide
Acetaldehyde	Acetaldehyde	Chemical Intermediate
Acetamide	Acetamide	Solvent/Plasticizer
Acetochlor	Acetochlor	Herbicide
Acetochlor ethane sulfonic acid	Acetochlor ethane sulfonic acid (ESA)	Herbicide degradant
Acetochlor oxanilic acid	Acetochlor oxanilic acid	Herbicide degradant
Acrolein	Acrolein	Chemical Intermediate
Alachlor ethanesulfonic acid	Alachlor ethanesulfonic acid	Herbicide degradant
Alachlor oxanilic acid	Alachlor oxanilic acid	Herbicide degradant
alpha-Hexachlorocyclohexane	*alpha*-Hexachlorocyclohexane	Former insecticide
Aniline	Aniline	Solvent/Intermediate
Bensulide	Bensulide	Herbicide
Benzyl chloride	Benzyl chloride	Chemical intermediate
Bromochloromethane (Halon 1101)	Bromochloromethane (Halon 1101)	Solvent/Fire Retardant/Water Disinfection Byproduct
Butylated hydroxyanisole	Butylated hydroxyanisole	Food Additive

[a] RD = Regulatory determination (The EPA's decision-making process of whether to propose regulations on contaminants within the CCL).

b RA = Regulatory action (The EPA determined that there was sufficient evidence for regulating strontium levels in water during the review of CCL 3).

Table 5C-1 (cont): Chemicals of Potential Human Health Concern Included in the EPA CCL 3 (2009) and CCL 4 (2016)

CCL 3, 2009	CCL 4, 2016	Use/Occurrence
Captan	Captan	Fungicide
Chlorate	Chlorate	Defoliant/Water Disinfection Byproduct
Chloromethane (Methyl chloride)	Chloromethane (Methyl chloride)	Foaming Agent/Chemical Intermediate
Clethodim	Clethodim	Herbicide
Cobalt	Cobalt	Inorganic Element, Naturally Occurring
Cumene hydroperoxide	Cumene hydroperoxide	Industrial Chemical
Cyanotoxins	Cyanotoxins	Natural toxins produced by Blue/Green algae
Dicrotophos	Dicrotophos	Insecticide
Dimethipin	Dimethipin	Herbicide
Dimethoate	Removed at CCL 3 RD[a]	Insecticide
Disulfoton	Removed during CCL 4 generation	Insecticide
Diuron	Diuron	Herbicide
Equilenin	Equilenin	Pharmaceutical/Hormone
Equilin	Equilin	Pharmaceutical/Hormone
Erythromycin	Erythromycin	Pharmaceutical/Antibiotic
Estriol	Estriol	Pharmaceutical/Hormone/Natural Product
Estrone	Estrone	Pharmaceutical/Hormone/Natural Product
Ethinyl estradiol	Ethinyl estradiol	Pharmaceutical
Ethoprop	Ethoprop	Insecticide
Ethylene glycol	Ethylene glycol	Antifreeze/Chemical intermediate
Ethylene oxide	Ethylene oxide	Insecticide/Fungicide
Ethylene thiourea	Ethylene thiourea	Chemical intermediate
Fenamiphos	Removed during CCL 4 generation	Insecticide
Formaldehyde	Formaldehyde	Natural Product/Water Disinfection Byproduct
Germanium	Germanium	Inorganic Element/Industrial Chemical
HCFC-22	HCFC-22	Refrigerant/Solvent
Hexane	Hexane	Solvent
Hydrazine	Hydrazine	Chemical intermediate

[a] RD = Regulatory determination (The EPA's decision-making process of whether to propose regulations on contaminants within the CCL).

[b] RA = Regulatory action (The EPA determined that there was sufficient evidence for regulating strontium levels in water during the review of CCL 3).

Table 5C-1 (cont): Chemicals of Potential Human Health Concern Included in the EPA CCL 3 (2009) and CCL 4 (2016)

CCL 3, 2009	CCL 4, 2016	Use/Occurrence
--	Manganese	Element/Nutrient/Chemical intermediate
Mestranol	Mestranol	Hormone Precursor/Pharmaceutical
Methamidophos	Methamidophos	Insecticide
Methanol	Methanol	Solvent
Methyl bromide (Bromomethane)	Methyl bromide (Bromomethane)	Fungicide/Fumigant
Methyl tert-butyl ether (MTBE)	Methyl tert-butyl ether (MTBE)	Solvent/Chemical intermediate/Gasoline additive
Metolachlor	Metolachlor	Herbicide
Metolachlor ethane sulfonic acid	Metolachlor ethane sulfonic acid	Herbicide degradant
Metolachlor oxanilic acid	Metolachlor oxanilic acid	Herbicide degradant
Molinate	Removed during CCL 4 generation	Herbicide
Molybdenum	Molybdenum	Element/Alloy
Nitrobenzene	Nitrobenzene	Solvent/Chemical intermediate
Nitroglycerin	Nitroglycerin	Pharmaceutical/Chemical intermediate
N-Methyl-2-pyrrolidone	N-Methyl-2-pyrrolidone	Solvent/Pharmaceutical excipient
N-nitrosodiethylamine (NDEA)	N-nitrosodiethylamine (NDEA)	Industrial Chemical/Cooking byproduct
N-nitrosodimethylamine (NDMA)	N-nitrosodimethylamine (NDMA)	Industrial Chemical/Cooking byproduct
N-nitroso-di-n-propylamine (NDPA)	N-nitroso-di-n-propylamine (NDPA)	Cooking and Water Disinfection Byproduct
N-nitrosodiphenylamine	N-nitrosodiphenylamine	Industrial Chemical/Water Disinfection Byproduct
N-nitrosopyrrolidine (NPYR)	N-nitrosopyrrolidine (NPYR)	Industrial Chemical/Cooking byproduct
	Nonylphenol	Chemical intermediate/Personal Care Products
Norethindrone	Norethindrone	Pharmaceutical
n-Propylbenzene	n-Propylbenzene	Solvent/Chemical intermediate/Asphalt component
o-Toluidine	o-Toluidine	Chemical intermediate
Oxirane, methyl-	Oxirane, methyl-	Chemical intermediate/Pesticide
Oxydemeton-methyl	Oxydemeton-methyl	Insecticide

[a] RD = Regulatory determination (The EPA's decision-making process of whether to propose regulations on contaminants within the CCL).

[b] RA = Regulatory action (The EPA determined that there was sufficient evidence for regulating strontium levels in water during the review of CCL 3).

Table 5C-1 (cont): Chemicals of Potential Human Health Concern Included in the EPA CCL 3 (2009) and CCL 4 (2016)

CCL 3, 2009	CCL 4, 2016	Use/Occurrence
Oxyfluorfen	Oxyfluoren	Herbicide
Perchlorate	2011 (+) Regulatory Determination	Chemical intermediate/Natural product
Permethrin	Permethrin	Insecticide
PFOA	PFOA	Surfactant/Flame retardant
PFOS	PFOS	Surfactant/Flame retardant
Profenofos	Profenofos	Insecticide
Quinoline	Quinoline	Chemical intermediate/Pharmaceutical
RDX	RDX	Munition
sec-Butylbenzene	sec-Butylbenzene	Solvent/Chemical intermediate
Strontium	Proposed for RA at RD[b]	Element/Chemical intermediate
Tebuconazole	Tebuconazole	Fungicide
Tebufenozide	Tebufenozide	Insecticide
Tellurium	Tellurium	Element
Terbufos	Removed at CCL 3 RD[a]	Insecticide
Terbufos sulfone	Removed at CCL 3 RD[a]	Insecticide degradant
Thiodicarb	Thiodicarb	Insecticide
Thiophanate-methyl	Thiophanate-methyl	Fungicide
Toluene diisocyanate	Toluene diisocyanate	Chemical intermediate
Tribufos	Tribufos	Insecticide/Defoliant
Triethylamine	Triethylamine	Chemical intermediate/Excipient
Triphenyltin hydroxide (TPTH)	Triphenyltin hydroxide (TPTH)	Pesticide
Urethane	Urethane	Paint and Coating ingredient
Vanadium	Vanadium	Element/Industrial catalyst
Vinclozolin	Vinclozolin	Fungicide
Ziram	Ziram	Fungicide

[a] RD = Regulatory determination (The EPA's decision-making process of whether to propose regulations on contaminants within the CCL).

[b] RA = Regulatory action (The EPA determined that there was sufficient evidence for regulating strontium levels in water during the review of CCL 3).

References

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EPA (2016). Drinking Water Contaminant Candidate List 4-Final.

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APPENDIX 5D: State of California Drinking Water Notification Levels

Chemical	Notification Level	
	mg/L	ng/L
Boron	1	1,000,000
n-Butylbenzene	0.26	260,000
sec-Butylbenzene	0.26	260,000
tert-Butylbenzene	0.26	260,000
Carbon disulfide	0.16	160,000
Chlorate	0.8	800,000
2-Chlorotoluene	0.14	140,000
4-Chlorotoluene	0.14	140,000
Diazinon	0.0012	1,200
Dichlorodifluoromethane (Freon 12)	1	1,000,000
1,4-Dioxane	0.001	1,000
Ethylene glycol	14	14,000,000
Formaldehyde	0.1	100,000
HMX	0.35	350,000
Isopropylbenzene	0.77	770,000
Manganese	0.5	500,000
Methyl isobutyl ketone (MIBK)	0.12	120,000
Naphthalene	0.017	17,000
N-Nitrosodiethylamine (NDEA)	0.00001	10
N-Nitrosodimethylamine (NDMA)	0.00001	10
N-Nitrosodi-n-propylamine (NDPA)	0.00001	10
Perfluorooctanoic acid (PFOA)	0.000014	14
Perfluorooctanesulfonic acid (PFOS)	0.000013	13
Propachlor	0.09	90,000
n-Propylbenzene	0.26	260,000
RDX	0.0003	300
Tertiary butyl alcohol (TBA)	0.012	12,000
1,2,4-Trimethylbenzene	0.33	330,000
1,3,5-Trimethylbenzene	0.33	330,000
2,4,6-Trinitrotoluene (TNT)	0.001	1,000
Vanadium	0.05	50,000

mg/L = Milligram per liter. ng/L = Nanogram per liter.

APPENDIX 5E: USDA MULTI-RESIDUE ANALYSIS OF FOOD ANIMAL TISSUES

Table 5E-1: Summary of the FSIS Multi-Residue Analysis of Food Animal Tissues Collected from Slaughter Establishments in the United States from October 2015 to April 2017. Priority rankings are provided by the EPA Office of Pesticide Programs (OPP), as reported by PEW (2016).

Analyte	EPA OPP Priority[A]	Log K_{OW}	FSIS Multi-Residue Analysis, Pesticides Minimum Level of Applicability (ng/g)[B] Bovine	Porcine	Poultry	Caprine	Ovine	n[C]	Samples > MLA (n) Oct 6, 2015 - Apr 19, 2017[D] Bovine	Porcine	Poultry	Caprine	Ovine
DDE o,p'	High	6.51	50	50	50	50	50	4,342	0	0	0	0	0
Tefluthrin	High	6.5	5	5	5	5	5	4,342	0	0	0	0	0
Pyridaben	High	6.37	9	9	9	9	9	4,362	0	0	0	0	0
Aldrin	High	6.3	25	25	25	25	25	4,329	0	0	0	0	0
Nonachlor cis	High	6.2	15	15	15	15	15	4,342	0	0	0	0	0
Nonachlor trans	High	6.2	15	15	15	15	15	4,342	0	0	0	0	0
Resmethrin (cis&trans)	High	6.1	50	50	50	50	50	4,362	0	0	0	0	0
DDD o,p'	High	6.02	50	50	50	50	50	4,342	0	0	0	0	0
Fenpropathrin	High	6	25	25	25	25	25	4,329	0	0	0	0	0
Hexythiazox	High	5.57	10	10	10	10	10	4,359	0	0	0	0	0
Sulprofos	High	5.48	25	25	25	25	25	4,362	0	0	0	0	0
Heptachlor	High	5.4	25	25	25	25	25	4,342	0	0	0	0	0
Pyriproxyfen	High	5.4	20	20	20	20	20	4,362	0	0	0	0	0
Pentachlorobenzene (PCB)	High	5.2	10	10	10	10	10	4,291	8	3	6	0	1
Pentachloroaniline (PCA)	High	5.08	25	25	25	25	25	4,342	0	0	0	0	0
Ethion	High	5.07	10	10	10	10	10	4,358	0	0	0	0	0
DDT p,p'	Highest	6.91	50	50	50	50	50	4,369	0	0	0	0	0
DDE p,p'	Highest	6.51	50	50	50	50	50	4,342	1	1	0	0	0
Permethrin (cis&trans)	Highest	6.5	25	25	25	25	25	4,343	3	0	0	0	0
Chlordane cis	Highest	6.16	10	10	10	10	10	4,342	0	0	0	0	0
Chlordane trans	Highest	6.16	10	10	10	10	10	4,342	0	0	0	0	0
Bifenthrin	Highest	6	5	5	5	N/App	5	4,329	0	0	0	0	1
Oxychlordane	Highest	6	10	10	10	10	10	4,342	0	0	0	0	0
Pyrethrin I	Highest	5.9	46	46	46	46	46	4,362	0	0	0	0	0
Pyrethrin II	Highest	5.9	31	31	31	31	31	4,362	0	0	0	0	0
Dieldrin	Highest	5.38	25	25	25	25	25	4,342	0	0	0	0	0
Hexachlorobenzene (HCB)	Highest	5.31	25	25	25	25	25	4,303	0	0	0	0	0
Ethion monoxon	Highest	5.07	10	10	10	10	10	4,358	0	0	0	0	0
Piperonyl butoxide	Highest	4.75	22.5	22.5	22.5	22.5	22.5	4,361	6	1	2	0	0
Chlorpyrifos	Highest	4.7	7.5	7.5	7.5	7.5	7.5	4,342	0	0	0	0	0
Endosulfan I	Highest	4.5	50	50	50	50	50	4,342	0	0	0	0	0
Fipronil	Highest	4	5	5	5	5	5	4,342	0	0	0	0	0
Endosulfan II	Highest	3.83	50	50	50	50	50	4,342	0	0	0	0	0
Diazinon	Highest	3.81	5	5	5	5	5	4,358	0	0	0	0	0
Lindane (BHC gamma)	Highest	3.72	40	40	40	40	40	4,343	0	0	0	0	0
MGK-264 (isomers 1 & 2)	Highest	3.7	50	50	50	50	50	4,342	0	0	0	0	0
Endosulfan sulfate	Highest	3.66	50	50	50	50	50	4,291	0	0	0	0	0
Chlorothalonil	Highest	3.05	60	60	60	60	60	4,182	2	4	0	0	1
Boscalid	Highest	2.95	15	15	15	15	15	4,358	0	0	0	0	0
1-Naphthol	Highest	2.85	30	30	30	30	30	4,183	10	3	4	0	0
Thiabendazole	Highest	2.47	15	15	15	15	15	4,362	0	0	0	0	0
Carbaryl	Highest	2.36	25	25	25	25	25	4,359	0	0	0	0	0
Acephate	Highest	-0.85	10	10	10	10	10	4,258	0	0	0	0	0
Heptachlor epoxide (cis+	Highest		25+25	25+25	25+25	25+25	25+25	4,194	0	0	0	0	0
Chlorpropham	Low	3.47	30	30	30	30	30	4,342	0	0	0	0	0
Pronamide	Low	3.43	5	5	5	5	5	4,343	0	0	0	0	0

Analyte	EPA OPP Priority[A]	Log K_{OW}	FSIS Multi-Residue Analysis, Pesticides Minimum Level of Applicability (ng/g)[B]					n[C]	Samples > MLA (n) Oct 6, 2015 - Apr 19, 2017[D]				
			Bovine	Porcine	Poultry	Caprine	Ovine		Bovine	Porcine	Poultry	Caprine	Ovine
Chloroneb	Low	3.4	9	9	9	9	9	4,342	0	0	0	0	0
Thiobencarb	Low	3.4	50	50	50	50	50	4,362	0	0	0	0	0
Carfentrazone ethyl	Low	3.36	5	5	5	5	5	4,358	0	0	0	0	0
Linuron	Low	3.2	25	25	25	25	25	4,360	0	0	0	0	0
Metolachlor	Low	3.13	10	10	10	10	10	4,329	0	0	0	0	0
Propanil	Low	3.07	25	25	25	25	25	4,361	0	0	0	0	0
Myclobutanil	Low	2.94	10	10	10	10	10	4,360	0	0	0	0	0
Malathion	Low	2.89	40	40	40	40	40	4,360	0	0	0	0	0
Atrazine	Low	2.75	10	10	10	10	10	4,358	0	0	0	0	0
Azinphos methyl	Low	2.75	10	10	10	10	10	4,358	0	0	0	0	0
Ethofumesate	Low	2.7	20	20	20	20	20	4,358	0	0	0	0	0
Benoxacor	Low	2.69	5	5	5	5	5	4,358	0	0	0	0	0
Diuron	Low	2.68	80	80	80	80	80	4,358	0	0	0	0	0
Azoxystrobin	Low	2.5	5	5	5	5	5	4,358	0	0	0	0	0
Carbofuran	Low	2.32	5	5	5	5	5	4,358	0	0	0	0	0
Norflurazon	Low	2.3	10	10	10	10	10	4,360	0	0	0	0	0
Simazine	Low	2.3	10	10	10	10	10	4,362	0	0	0	0	0
Fluroxypyr-1-Methylhepyl-	Low	2.2	5	5	5	5	5	4,358	0	0	0	0	0
Propachlor	Low	2.18	10	10	10	10	10	4,361	0	0	0	0	0
Fluridone	Low	1.87	25	25	25	25	25	4,358	0	0	0	0	0
Metribuzin	Low	1.7	50	50	50	50	50	4,360	0	0	0	0	0
Metalaxyl	Low	1.65	10	10	10	10	10	4,360	0	0	0	0	0
Coumaphos S	Low	1.58	10	10	10	10	10	4,358	0	0	0	0	0
Dichlorvos (DDVP)	Low	1.58	10	10	10	10	10	4,358	0	0	0	0	0
Hexazinone	Low	1.2	30	30	30	30	30	4,359	0	0	0	0	0
Acetamiprid	Low	0.8	5	5	5	5	5	4,358	0	0	0	0	0
Methomyl	Low	0.8	30	30	30	30	30	4,360	0	0	0	0	0
Dimethoate	Low	0.76	10	10	10	10	10	4,358	0	0	0	0	0
Clothianidin	Low	0.7	10	10	10	10	10	4,358	0	0	0	0	0
Imidacloprid	Low	0.57	25	25	25	25	25	4,359	0	0	0	0	0
3-Hydroxycarbofuran	Low	0	5	5	5	5	5	4,358	0	0	0	0	0
Coumaphos O	Low	0	10	10	10	10	10	4,358	0	0	0	0	0
Thiamethoxam	Low	-0.13	10	10	10	10	10	4,362	0	0	0	0	0
Omethoate	Low	-0.74	10	10	10	10	10	4,360	0	0	0	0	0
Methamidophos	Low	-1.74	10	10	10	10	10	4,361	0	0	0	0	0
Aldicarb	Low	1.13	10	10	10	10	10	4,358	0	0	0	0	0
Aldicarb sulfone	Low	1.13	10	10	10	10	10	4,358	0	0	0	0	0
Aldicarb sulfoxide	Low	1.13	25	25	25	25	25	4,359	0	0	0	0	0
Indoxacarb	Medium	4.65	25	25	25	25	25	4,360	0	0	0	0	0
Fenoxaprop ethyl	Medium	4.58	10	10	10	10	10	4,358	0	0	0	0	0
Trifloxystrobin	Medium	4.5	5	5	5	5	5	4,362	0	0	0	0	0
Profenofos	Medium	4.44	10	10	10	10	10	4,361	0	0	0	0	0
Chlorpyrifos methyl	Medium	4.37	5	5	5	5	5	4,342	0	0	0	0	0
Buprofezin	Medium	4.3	25	25	25	25	25	4,358	0	0	0	0	0
Fluvalinate	Medium	4.26	7.5	7.5	7.5	7.5	7.5	4,343	0	0	0	0	0
Tebufenozide	Medium	4.25	40	40	40	40	40	4,362	0	0	0	0	0

Analyte	EPA OPP Priority[A]	Log K_{ow}	FSIS Multi-Residue Analysis, Pesticides Minimum Level of Applicability (ng/g)[B] Bovine	Porcine	Poultry	Caprine	Ovine	n[C]	Samples > MLA (n) Oct 6, 2015 - Apr 19, 2017[D] Bovine	Porcine	Poultry	Caprine	Ovine
Difenoconazole	Medium	4.2	15	15	15	15	15	4,358	0	0	0	0	0
Pirimiphos methyl	Medium	4.2	10	10	10	10	10	4,360	0	0	0	0	0
Diflubenzuron	Medium	3.89	12.5	12.5	12.5	12.5	12.5	4,358	1	0	0	0	0
Imazalil	Medium	3.82	5	5	5	5	5	4,359	0	3	1	2	0
Propetamphos	Medium	3.82	7.5	7.5	7.5	7.5	7.5	4,362	0	0	0	0	0
Propiconazole	Medium	3.72	15	15	15	15	15	4,362	0	0	0	0	0
Methoxyfenozide	Medium	3.7	5	5	5	5	5	4,360	0	0	0	0	0
Prallethrin	Medium	3.7	40	40	40	40	40	4,361	0	0	0	0	0
Pyraclostrobin	Medium	3.58	50	50	50	50	50	4,362	0	0	0	0	0
Tetraconazole	Medium	3.56	5	5	5	5	5	4,362	0	0	0	0	0
Alachlor	Medium	3.53	5	5	5	5	5	4,358	0	0	0	0	0
Tetrachlorvinphos	Medium	3.53	10	10	10	10	10	4,362	0	0	0	0	0
DDD p,p' + DDT, o,p'	NR[E]		50+50	50+50	50+50	50+50	50+50	4,342	0	0	0	0	0
Fipronil desulfinyl	NR		5	5	5	5	5	4,342	0	0	0	0	0
Fipronil sulfide	NR		5	5	5	5	5	4,342	1	0	0	0	0
Deethylatrazine	NR		10	10	10	10	10	4,358	0	0	0	0	0

[A] Prioritization for FSIS measurement by the US Environmental Protection Agency; Supplemental Appendix F of Pew (2016).

[B] Minimum Level of Applicability, FSIS (2016).

[C] Total number of samples analyzed using a multi-residue screening assay. Concentrations of residues in samples above the MLA and that meet other required criteria must be confirmed using a quantitative confirmatory assay.

[D] Data from FSIS (n.d.).

[E] Not ranked but measured in the multi-residue analysis.

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APPENDIX 5F: HUMAN HEALTH AND SAFETY—RESIDUE AND CLEARANCE

Although regulatory agencies play a major role in chemical food safety, the foremost reason that toxic chemical residues are rarely encountered in food animal products is because most chemicals are rapidly cleared from the body. The term "chemical residue" describes the sum of a parent compound and its metabolites and/or degradants that remain in meat after an animal has been slaughtered. The long-term accumulation of residues does not occur for *most* chemicals because food animals—and people—efficiently clear and eliminate chemicals of no nutritional value. Such chemicals are cleared by two primary mechanisms: metabolism and/or elimination.

Metabolism is the enzymatic process of altering the physiochemical properties of chemicals through the addition of polar functional groups (Parkinson et al., 2013). Metabolism usually increases water solubility and facilitates increased rates of metabolite elimination relative to the parent compound. The variety of documented chemical transformations that occur during chemical clearance is broad, and categories of reactions include: hydrolysis (esterases, oxonases, phosphatases, glucuronidases, hydrolases); reduction (azo-, nitro-, carbonyl-, disulfide- sulfoxide-, quinone-, dehydrogenases, dehalogenation, dehydroxylases); oxidation (Cytochrome P450, flavin monoxygenases); and conjugation (glucuronosyl, amino acid, glutathione, methyl, acetyl). While the total number of these reactions may appear modest, those listed are highly abbreviated with respect to the collective body of enzymes contributing to xenobiotic clearance. For example, within the Cytochrome P450 family, at least 57 different human isozymes have been described (Zanger and Schwab, 2013).

Due to their relatively broad substrate specificities and broad distribution throughout body tissues, xenobiotic-metabolizing enzymes eliminate many diverse xenobiotic classes (industrial chemicals, natural toxins, personal care products, pharmaceuticals, endogenous hormones, endocrine disrupting compounds). Nevertheless, the enzymes that metabolize a specific xenobiotic and the resulting pathway of elimination depends on the properties of the parent compound. For example, highly water-soluble chemicals ($\log_{10} P < 0$) may undergo renal elimination without transformation, whereas compounds with intermediate ($\log_{10} P = 0$ to 5) to low ($\log_{10} P > 5$) water solubility generally require modest to extensive metabolism.[39]

Highly lipophilic compounds, especially those resistant to metabolism (i.e., compounds with a high degree of halogenation), may accumulate in fatty tissues and have prolonged elimination half-lives in animals and people. When such molecules are toxic at low doses, concern for long-term human exposures occur. The Stockholm Convention on persistent organic pollutants (POPs) compiles a roster of the highest priority bioaccumulative, potentially toxic chemicals; these xenobiotics are targeted for regulatory elimination or production restrictions in signatory countries. Typically, such compounds are on the EPA's CCL list if water is a noteworthy exposure source. Elemental compounds (metals and metal

39 The partition coefficient (Log P) is a measure of differential solubility of a compound in a hydrophobic solvent (octanol) and a hydrophilic solvent (water). The logarithm of these two values enables compounds to be ranked in terms of hydrophilicity (or hydrophobicity) (Savjani et al. (2012).

oxides) of concern may also bioaccumulate even though they are not particularly lipophilic. Metals and transition metals of toxicological concern generally are absorbed and retained via the same transporters and storage mechanisms as essential elemental nutrients (Fe, Zn, Cu, Se, etc.). It is for this reason that elements with no known physiologic function (cadmium, lead) can accumulate in animals and people (Tokar et al., 2013).

Once absorbed, however, most xenobiotic compounds are metabolized and eliminated through urine, feces (through biliary excretion or non-absorption), respiration (of mineralized or volatile metabolites), sweat, and/or milk and eggs. Because xenobiotic metabolism and elimination normally occur with high efficiency, it is difficult for most trace-level xenobiotic residues to accumulate to levels that cause measurable physiologic response in a recipient animal. That is, most pharmaceuticals and personal care products present in municipal waste and tertiary wastewaters (Anderson et al., 2010) are present in those waters because they were efficiently eliminated from people.

Disinfection by-products (DBPs) formed during water disinfected with chlorination (trihalomethanes), hypochlorite treatment (chlorate, perchlorate, bromate), chlorine dioxide (chlorate), or ozone (bromate, N-nitroso compounds such as NDMA) will, by definition, be present in DTRW. As such, food animals watered with DTRW will be exposed to DBPs. Rapid clearance of DBPs might be predicted because of they are highly water soluble, and the available data confirms this notion. For example, Table 5G-1 shows that the half-lives of DBPs in test animals are rapid, ranging from <1 hour to 11 hours depending on several variables including dose, route of exposure, and species. The consistent theme, however, is that rapid elimination precludes accumulation of chemical residue. A consequence of rapid clearance is that eggs or meats from food animals watered with DTRW would represent an insignificant exposure pathway to DBPs compared to direct exposures through drinking water, showering, or swimming (see discussion by Richardson et al, 2007).

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APPENDIX 5G: KNOWN HALF-LIFE OF DBPS

Table 5G-1: Known half-lives of DBPs illustrate rapid clearance from the body following absorption.

Compound	Log P	Species	Half-life	Matrix	Reference
Bromate	0.63[a]	Rat	< 1 hr. (plasma)	Plasma	Bull et al. 2012
Chlorate	-2.9[b]	Sheep	2.5 to 6.2 hr.	Serum	Smith and Taylor, 2012;
		Cattle	6.9 to 11 hr.	Serum	Oliver et al., 2007
		Swine	<12 hr.	Urine	Smith et al., 2006a
Nitrate	-3.8[c]	Human	8.1 – 13.3 hr.	Plasma	Hunault et al., 2009
		Sheep	4.2 hr.	Plasma	Schneider and Yeary, 1975
Nitrite		Human	0.4 - 0.6 hr.	Plasma	Hunault et al., 2009
		Sheep	0.5 hr.	Plasma	Schneider and Yeary, 1975
Perchlorate	-7.18[d]	Goat	2.3 hr.	Serum	Smith et al., 2006b
		Rat	7.3 hr.	Plasma	Yu et al., 2002
Tribromomethane	2.38[e]	Rat	0.8 hr.	Whole body	Mink et al., 1986
		Mouse	8 hr.	Whole body	Mink et al., 1986
Trichloromethane	1.97[e]	Rat	2 hr.	Whole body	Mink et al., 1986
		Mouse	2 hr.	Whole body	Mink et al., 1986
Bromodichloromethane	2.0[f]	Rat	5 hr. (1-10 mg/kg)	Whole body	Mathews et al., 1990
		Rat	17 hr. (100 mg/kg)	Whole body	Mathews et al., 1990
		Rat	1.5 hr.	Whole body	Mink et al., 1986
		Mouse	2.5 hr.	Whole body	Mink et al., 1986
N-Nitrosodimethylamine	-0.57[g]	Dogs	0.7 to 0.9 hr.	Blood	Gombar et al., 1987
		Rat	0.24 hr.	Blood	Streeter et al., 1990
		Swine	0.8 hr. to 1.1 hr.	Blood	Gombar et al., 1988
1,4 dioxane	-0.27[h]	Rat	1.1 hr.	Plasma	Young et al., 1978

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BIOGRAPHIES OF THE PANEL MEMBERS

CHAIR: Robert Poppenga, DVM, PhD, DABVT

Professor of Veterinary Diagnostic and Clinical Toxicology, California Animal Health and Food Safety Laboratory, School of Veterinary Medicine, University of California Davis (Davis, CA)

Robert Poppenga is Senior Toxicologist and Head of the Toxicology Section of the California Animal Health and Food Safety Laboratory System. Dr. Poppenga's expertise in toxicology extends to environmental contamination, chemical food safety, risk assessment, pharmacovigilance, chemical agroterrorism, and diagnostic veterinary medicine. He has served as a lead investigator in the National Food Emergency Response Network, including during the 2007 Nationwide Pet Food Recall and the 2010 Gulf of Mexico Oil Spill. Dr. Poppenga has authored more than 200 published contributions to peer-reviewed papers, professional meeting proceedings, and books. He holds a PhD in Veterinary Toxicology and a DVM from University of Illinois at Urbana-Champaign.

Nicholas Ashbolt, PhD

Professor, School of Public Health, University of Alberta (Edmonton, Alberta, Canada)

Nicholas Ashbolt has more than 25 years of experience working with water supply systems. His research focuses on next-generation municipal water services (drinking water, wastewater, stormwater) framed around resource recovery (i.e. water, energy, fertilizers) for improved ecohealth and living conditions. Prior to joining the School of Public Health at the University of Alberta, Dr. Ashbolt served as a research microbiologist for US Environmental Protection Agency (EPA) and earned the US EPA Office of Research and Development Bronze Awards for science in 2008, 2012, and 2013. His current activities include developing water safety plan-based regulations in Canada and applying quantitative microbial risk assessment to municipal and agricultural water reuse projects. He was a professor in the School of Civil and Environmental Engineering at University of New South Wales–Sydney for 14 years. Dr. Ashbolt has authored or co-authored more than 200 peer-reviewed journal articles and 35 book chapters. He holds a PhD in environmental microbiology from University of Tasmania.

Andrea Mikolon, DVM, MPVM, PhD

Veterinarian Specialist (Binational Liaison), California Department of Food and Agriculture, Animal Health Branch (San Diego, CA)

Andrea Mikolon is a veterinary epidemiologist and serves as the Binational Liaison for Animal Health for the California Department of Food & Agriculture (CDFA). She spent three years in Baja California, Mexico, conducting dissertation research on the epidemiology of Brucella melitensis. Dr. Mikolon has worked for the US Centers for Disease Control & Prevention (CDC) in Bangladesh as the Head of the Zoonotic Disease Research Group at the International Centre for Diarrhoeal Disease Research and later,

for USDA Animal and Plant Health Inspection Service (APHIS) Veterinary Services (VS) as a port veterinarian and biosafety inspector. Dr. Mikolon has worked a total of 10 years for CDFA, serving as an epidemiologist on numerous disease outbreaks in livestock and poultry. She represents the State Veterinarian at binational meetings and on reviews of Mexican states to determine disease status for purposes of livestock trade. Dr. Mikolon graduated from University of California at Davis with a DVM, MPVM, and PhD in epidemiology with an emphasis on infectious disease.

Brian Pecson, PhD, PE

Water Process Engineer, Trussell Technologies (Oakland, CA)

Brian Pecson has expertise in disinfection and pathogens, and currently focuses on a number of projects related to both non-potable and potable reuse, in which wastewater is treated to drinking water standards. His work in this area includes the development of public health criteria for potable reuse, and the design, evaluation, and testing of reuse technologies that can reliably protect the public from both chemical contaminants and pathogenic microorganisms. Through these projects, Dr. Pecson is working with the California State Water Resources Control Board's Division of Drinking Water to advance and expand options for the design, implementation, and permitting of innovative potable reuse systems. He is also interested in residuals management, including brine streams, industrial wastes, and sludges. Dr. Pecson holds an MS and PhD in civil and environmental Engineering from the University of California at Berkeley, and a BS and BA from the University of Notre Dame. He is a registered engineer in the state of California with more than 15 years of experience. Dr. Pecson has authored 14 research papers on topics ranging from pathogen disinfection to public health protection.

Channah Rock, PhD

Water Quality Extension Specialist and Associate Professor, University of Arizona (Tucson, AZ)

Channah Rock serves as a Water Quality Extension Specialist and Associate Professor in the Department of Soil, Water, and Environmental Science at the University of Arizona. Her research interests include microbiology, molecular biology, and wastewater treatment. She evaluates water quality for the protection of public health and promotes water reuse as a safe and practical resource. Her background in both microbiology and civil and environmental engineering has focused her work on understanding the factors that influence pathogens' survival through water treatment and their persistence in the environment. Dr. Rock received a BS in microbiology from New Mexico State University and an MS and PhD in civil and environmental engineering from Arizona State University. She conducted post-doctoral research at the US Department of Agriculture's Agricultural Research Service.

David J. Smith, PhD

Research Leader, Animal Metabolism-Agricultural Chemicals Research, United States Department of Agriculture, Agricultural Research Service (Fargo, ND)

David Smith is a Supervisory Research Physiologist at the USDA ARS Biosciences Research Laboratory in Fargo, North Dakota. He leads the Animal Metabolism-Agricultural Chemicals Research Unit, the mission of which is to investigate the absorption, distribution, metabolism, and excretion of natural toxins, persistent organic pollutants, veterinary drugs, and other bioactive chemicals in food animal species. Dr. Smith has published more than 190 peer-reviewed journal articles, regulatory submissions (EPA, FDA CVM), book chapters, books, proceeding papers, and abstracts. He holds a BS in animal and range sciences from New Mexico State University, and an MS and PhD in animal sciences from Washington State University.