Reuse of CAFO Wastewater on Agricultural Lands: Potential Environmental Contaminants, Transport Pathways and Treatments

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CAFO Wastes

- US generates around 500 million tons of manure annually.
- Livestock water use accounts for 1% of total freshwater withdrawals.
- Large volumes of manure-containing wastewater, wash water, and storm water runoff can be generated at CAFOs.
- Manure-contaminated water is typically stored in wastewater lagoons before land application.

Salts in Select CAFO Lagoon Water

CAFO Operation	EC dS m^{-1}	TKN mg L^{-1}	TP mg L^{-1}	TOC mg L^{-1}	Cu mg L^{-1}	Zn mg L^{-1}
Beef Feedlot[2]	2.6 ± 0.0	63 ± 1	14 ± 0	155 ± 6	0.02 ± 0.00	0.41 ± 0.45
Dairy[2]	3.1 ± 0.0	185 ± 11	30 ± 1	576 ± 94	0.66 ± 0.06	0.42 ± 0.05
Poultry[1]	11.3 ± 0.2	802 ± 7	50 ± 1	1050 ± 40	1.65 ± 0.02	0.75 ± 0.08
Poultry[2]	8.0 ± 0.0	407 ± 2	23 ± 0	374 ± 15	0.05 ± 0.00	0.27 ± 0.02
Poultry[3]	4.4 ± 0.0	96 ± 0	30 ± 0	114 ± 15	0.01 ± 0.00	0.08 ± 0.00
Swine Sow[1]	12.6 ± 0.0	1290 ± 15	264 ± 5	944 ± 304	0.38 ± 0.01	15.2 ± 0.14
Swine Finisher[1]	19.4 ± 0.0	2430 ± 40	324 ± 14	4780 ± 280	6.87 ± 4.60	10.5 ± 0.58
Swine Nursery[1]	21.5 ± 0.1	2040 ± 60	368 ± 35	1440 ± 130	13.3 ± 2.1	109 ± 21

- Salts – May alter many soil physical and chemical properties, and crop yields. Associated yield problems are due to specific ion toxicities and osmotic stress. Restriction on use for irrigation: < 0.7 dS m^{-1} none; >3.0 dS m^{-1}Severe.

Nutrients and Organics in Select CAFO Lagoon Water

CAFO Operation	EC dS m^{-1}	TKN mg L^{-1}	TP mg L^{-1}	TOC mg L^{-1}	Cu mg L^{-1}	Zn mg L^{-1}
Beef Feedlot[2]	2.6 ± 0.0	63 ± 1	14 ± 0	155 ± 6	0.02 ± 0.00	0.41 ± 0.45
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- Nutrients (MCL=10 ppm for nitrate) and Organics – Excess nutrients and organics can contribute to algal blooms, reduced biodiversity, objectionable tastes and odors, and growth of toxic organisms. Associated hypoxia/anoxia and high ammonia have caused major kills of freshwater species. Increased risk of methemoglobinemica, diarrhea and respiratory disease in humans.

Heavy Metals in Select CAFO Lagoon Water

CAFO Operation	EC dS m^{-1}	TKN mg L^{-1}	TP mg L^{-1}	TOC mg L^{-1}	Cu mg L^{-1}	Zn mg L^{-1}
Beef Feedlot[2]	2.6 ± 0.0	63 ± 1	14 ± 0	155 ± 6	0.02 ± 0.00	0.41 ± 0.45
Dairy[2]	3.1 ± 0.0	185 ± 11	30 ± 1	576 ± 94	0.66 ± 0.06	0.42 ± 0.05
Poultry[1]	11.3 ± 0.2	802 ± 7	50 ± 1	1050 ± 40	1.65 ± 0.02	0.75 ± 0.08
Poultry[2]	8.0 ± 0.0	407 ± 2	23 ± 0	374 ± 15	0.05 ± 0.00	0.27 ± 0.02
Poultry[3]	4.4 ± 0.0	96 ± 0	30 ± 0	114 ± 15	0.01 ± 0.00	0.08 ± 0.00
Swine Sow[1]	12.6 ± 0.0	1290 ± 15	264 ± 5	944 ± 304	0.38 ± 0.01	15.2 ± 0.14
Swine Finisher[1]	19.4 ± 0.0	2430 ± 40	324 ± 14	4780 ± 280	6.87 ± 4.60	10.5 ± 0.58
Swine Nursery[1]	21.5 ± 0.1	2040 ± 60	368 ± 35	1440 ± 130	13.3 ± 2.1	109 ± 21

- Heavy metals are sometimes added to animal feed to promote growth (e.g., arsenic is fed to chickens, and copper and zinc to swine). Possible risks of this practice include phytotoxicity (Cu>0.2 mg L^{-1}; Zn>2 mg L^{-1}), and surface and groundwater contamination.

Hormones in Select CAFO Lagoon Water

CAFO Operation	Estrone ng L^{-1}	17-α-Estradiol ng L^{-1}	17-β-Estradiol ng L^{-1}	Estriol ng L^{-1}	E1-3S ng L^{-1}	E2α-3S ng L^{-1}	E2β-3S ng L^{-1}	E2β-17S ng L^{-1}
Beef Feedlot[2]	17 ± 1	6 ± 1	< 20	< 8	< 1	< 1	< 1	< 1
Dairy[2]	76 ± 12	229 ± 56	153 ± 34	< 8	87 ± 4	166 ± 22	42 ± 3	< 1
Poultry[1]	2970 ± 150	408 ± 37	64 ± 9	489 ± 49	1 ± 1	< 1	< 1	< 1
Poultry[2]	1570 ± 80	131 ± 15	21 ± 10	190 ± 5	3 ± 1	< 1	10 ± 3	< 1
Poultry[3]	21 ± 2	< 4	< 20	< 8	< 1	< 1	< 1	< 1
Swine Sow[1]	10500 ± 1260	1220 ± 70	211 ± 128	6290 ± 850	2 ± 0	< 1	< 1	80 ± 7
Swine Finisher[1]	1640 ± 10	184 ± 24	152 ± 44	1540 ± 30	< 1	< 1	< 1	< 1
Swine Nursery[1]	834 + 73	74 + 3	46 + 32	353 + 478	< 1	< 1	< 1	< 1

E1-3S = Estrone-3-sulfate; E2a-3S = 17α - estradiol-3-sulfate; E2b-3S = 17β-estradiol-3-sulfate; E2b-17S = 17β-estradiol-17-sulfate

- Steroid hormones are highly potent endocrine-disrupting chemicals which may interfere with the normal function of endocrine systems of humans and animals. Animal waste may account for >90% in the environment. Hormones adversely affect the reproduction of fish and other aquatic species a very low concentrations (ng L^{-1}).

Antibiotics in Select CAFO Lagoon Water

CAFO Operation	TC µg L^{-1}	OxyTC µg L^{-1}	ChloroTC µg L^{-1}	Iso-chloroTC µg L^{-1}	Epi-iso-chloroTC µg L^{-1}	Sulfamethazine µg L^{-1}	Lincomycin µg L^{-1}	Tylosin µg L^{-1}
Beef Feedlot[2]	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.05 ± 0.08
Dairy[2]	0.13 ± 0.07	< 0.01	< 0.01	0.01 ± 0.01	0.05 ± 0.08	< 0.01	0.01 ± 0.00	< 0.01
Poultry[1]	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01 ± 0.02
Poultry[2]	< 0.01	< 0.01	< 0.01	0.02 ± 0.02	0.01 ± 0.01	< 0.01	< 0.01	< 0.01
Poultry[3]	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01 ± 0.01	< 0.01
Swine Sow[1]	0.84 ± 1.45	< 0.01	0.54 ± 0.47	26.7 ± 3.2	19.7 ± 2.6	< 0.01	1.73 ± 1.52	< 0.01
Swine Finisher[1]	6.61 ± 6.50	0.14 ± 0.24	7.51 ± 6.73	97.3 ± 16.8	53.3 ± 5.1	< 0.01	1340 ± 480	0.33 ± 0.30
Swine Nursery[1]	< 0.01	68.0 ± 15.4	< 0.01	53.3 ± 9.3	22.3 ± 4.5	2.36 ± 1.22	38.0 ± 8.5	< 0.01

TC = Tetracycline

- Antibiotics are used in CAFOs as a therapeutic, for growth-improvement, and health-protection. As much as 80% of the antibiotics are excreted in animal wastes. Potential environmental risks are due to development of antibiotic resistant organisms and altering natural ecosystem functions.

Indicator Microorganisms in Select CAFO Lagoon Water

CAFO Operation	Total Coliforms cfu per 100 mL	Fecal Coliforms cfu per 100 mL	Fecal Enterococci cfu per 100 mL
Beef Feedlot[2]	3.89E03 ± 0.99E03	1.57E03 ± 0.28E03	2.94E03 ± 1.07E03
Dairy[2]	1.91E07 ± 0.16E07	1.08E06 ± 0.11E06	1.53E05 ± 0.23E05
Poultry[1]	4.73E04 ± 2.09E04	2.91E04 ± 1.07E04	1.41E05 ± 0.67E05
Poultry[2]	2.42E03 ± 0.00E03	2.42E03 ± 0.00E03	8.51E04 ± 2.75E04
Poultry[3]	5.83E04 ± 0.28E04	2.03E01 ± 0.06E01	2.68E03 ± 1.24E03
Swine Sow[1]	4.89E05 ± 0.70E05	3.34E05 ± 0.43E05	3.69E05 ± 0.39E05
Swine Finisher[1]	1.02E06 ± 0.12E06	9.52E05 ± 3.44E05	8.50E05 ± 4.63E05
Swine Nursery[1]	1.87E05 ± 0.95E05	7.93E04 ± 8.30E04	2.43E05 ± 0.00E05

- Animal wastes frequently contain pathogenic viruses, bacteria, and protozoa that pose a risk to human and/or animal health. Pathogens in groundwater have been estimated to cause between 0.75 to 5 million illnesses in the US per year. Manure-contaminated water resources have also been implicated in food borne disease outbreaks on a variety of fresh produce (e.g., spinach). The unrestricted irrigation water standard is <1000 CFU of FC per 100 mL.

Potential Benefits of CAFO Wastes

- Fertilizer and soil amendment that improves the physical and biogeochemical conditions of soil.
- Reduce demand for high quality water that is a scarce natural resource in many arid and semi-arid regions.

Additional Considerations

- Transportation, storage, and treatment of CAFO wastes are costly.
- We need economically viable CAFOs to produce products that we consume.

Current Regulatory Framework

Nutrient Management Plans

- Application of CAFO wastes at agronomic rates.
- Developed from state specific NRCS guidelines.
- Typically written to be protective of surface water resources.
- Limited direction on land application site characterization and design to protect groundwater resources.

Contaminant Loading at a NMP Site

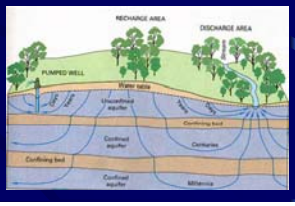
- Total salts, metals, antibiotics, estrogen hormones, and indicator microorganisms when the various (diluted) lagoon waters were applied to a 1 m^2 area of agricultural field to meet the nitrogen needs of corn during a 90 day summer growing season. An ET rate of 10 mm per day was assumed.

CAFO Operation	Blending Ratio	Total Salts g m^{-2}	Total Metals (Zn+Cu) mg m^{-2}	Total Estrogen Hormones µg m^{-2}	Total Antibiotic µg m^{-2}	Total Indicator Microbes N m^{-2}
Beef Feedlot[2]	0.93	1755.0	387.00	49.50	108.00	6.1E+07
Dairy[2]	4.56	458.9	213.16	150.39	45.39	3.8E+10
Poultry[1]	27.46	277.8	78.66	128.97	2.62	6.2E+07
Poultry[2]	12.79	422.2	22.52	122.23	4.93	6.2E+07
Poultry[3]	20.7	1434.8	39.13	24.78	34.78	2.7E+08
Swine Sow[1]	43.22	196.8	324.43	250.20	475.61	1.8E+08
Swine Finisher[1]	80.21	163.3	194.90	22.22	15797.41	2.1E+08
Swine Nursery[1]	67.19	216.0	1638.19	12.83	1750.57	5.8E+07

NMP Environmental Issues – Water

- NMP Assumption: No surface water runoff or leaching to groundwater.
- It is difficult to accurately account for all sources of water; e.g., irrigation, precipitation, surface water, snow melt, soil water, and shallow water tables.
- Nonuniform water application occurs during flood or furrow irrigation or as a result of spatial variability in soil hydraulic properties or ET.
- Preferential flow of water may bypass portions of the root zone before plants can uptake the water.

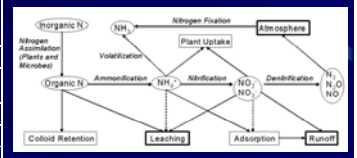
Water in excess of PET will produce surface runoff and/or leaching of contaminants!



NMP Environmental Issues – Nutrient

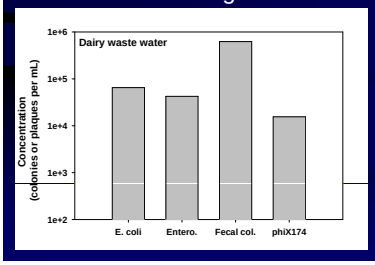
- NMP Assumption: The most critical concern is the limiting nutrient balance.
- There are differences in the nutrient composition of the lagoon water and the plant nutrient uptake rates.
  - If phosphorus is the limiting nutrient, then little lagoon water is used and nitrogen fertilizer has to be added.
  - If nitrogen is the limiting nutrient, then phosphorus is applied in excess.
- Different transport potential for various nutrient species
- Complex geochemistry

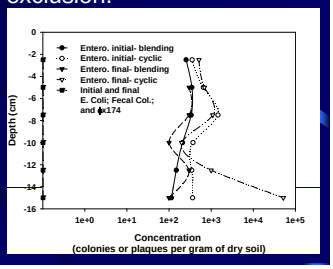
Crop	Nitrogen kg per ton of product	Phosphorus kg per ton of product
Corn for silage	3.2	0.5
Sorghum for silage	6.7	1.1
Barley	17.0	3.4
Wheat	18.7	3.3
Alfalfa	22.9	2.1
Grass silage	6.2	0.7



NMP Environmental Issues – Pathogens

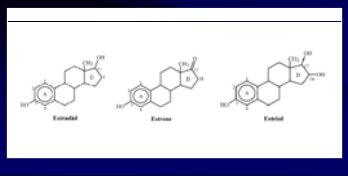
- NMP Assumption: Pathogens will be retained in the root zone and will not survive for long periods of time.
- Retention of pathogens is highly dependent on physical, chemical, and microbiological characteristics of the site.
- Long-term pathogen survival in manure and soil environments has been demonstrated in the literature (temperature, water content, nutrients, etc.).
- Potential for regrowth and size exclusion.

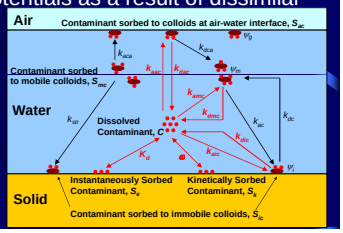




NMP Environmental Issues – Hormones and Antibiotics

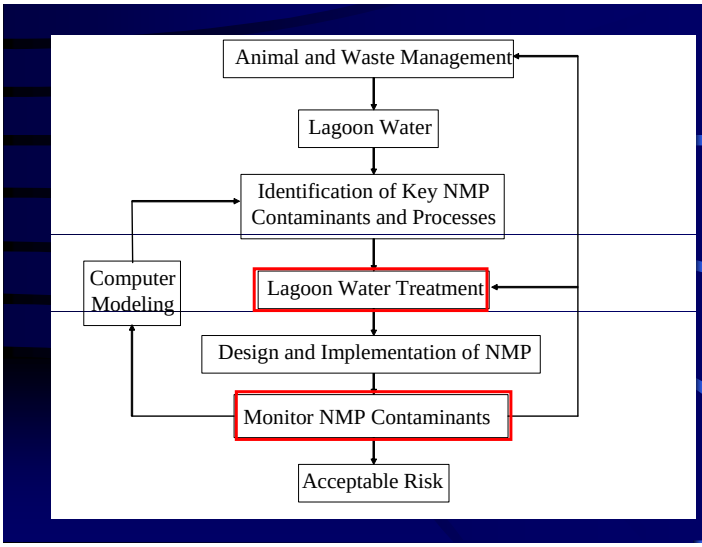
- NMP Assumption: Hormones and antibiotics will be degraded in the root zone.
- Most are hydrophobic compounds which sorb strongly to the organic fraction of soils.
- May also be associated with high numbers of organic colloids. Potential exists for colloid facilitate transport.
- Complex degradation pathways and sequences occur that are dependent on the temperature, water content, nutrients, and microbial community.
- Metabolites are also of health concern, and may possess significantly different transport potentials as a result of dissimilar degradation and sorption rates.



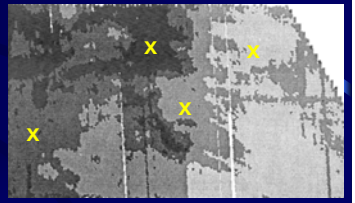


NMP Environmental Issues – Salts and Heavy Metals

- NMP Assumption: Salt and heavy metal accumulation will not impact crop yields or soil conditions.
- If water is applied to meet PET, then salts will accumulate in the root zone.
- Salt accumulation will eventually influence crop yields and soil quality.
- Leaching of salts may be unacceptable to regulators. For example, in Chino, CA dairy farmers have had to pay for a desalination plant to offset salt loads to groundwater.



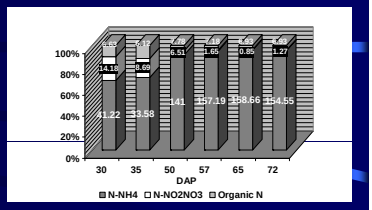
Monitoring Lagoon Water Contaminants



EM map of the field site

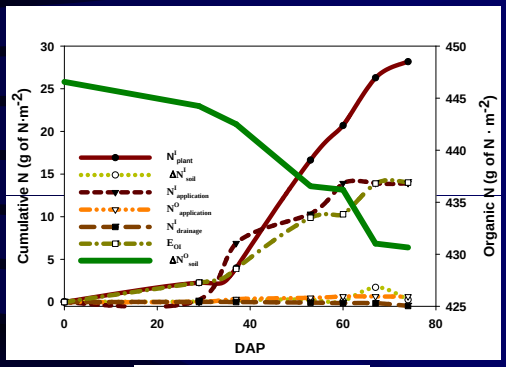
Lagoon Water Treatment

- Inclined screen, sedimentation tank, and sand filter.



Indicator	Raw	Treated	% Removal
Enterococcus (cfu ml^{-1})	1.56E+06	6.10E+04	96.1
fecal coliform (cfu ml^{-1})	2.47E+05	6.00E+03	97.6
somatic coliphage (pfu ml^{-1})	7.50E+03	5.00+02	93.3
total *E. coli* (cfu ml^{-1})	9.30E+04	3.00E+03	96.8

Water and N Mass Balance



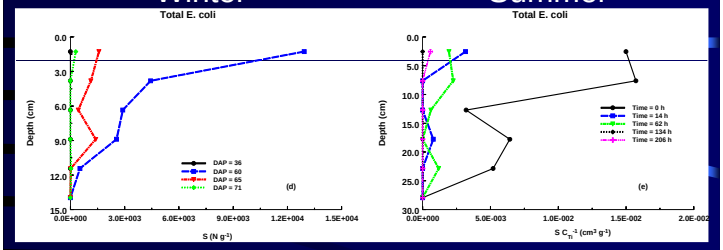
$$I = ET + D + \Delta W - P_w$$

$$N^I_{application} + E_{OI} = N^I_{plant} + N^I_{drainage} + N^I_{atmosphere} + \Delta N^I_{soil}$$

$$N^O_{application} = \Delta N^O_{soil} + E_{OI}$$

NMP Field – Total E. coli

Winter Summer

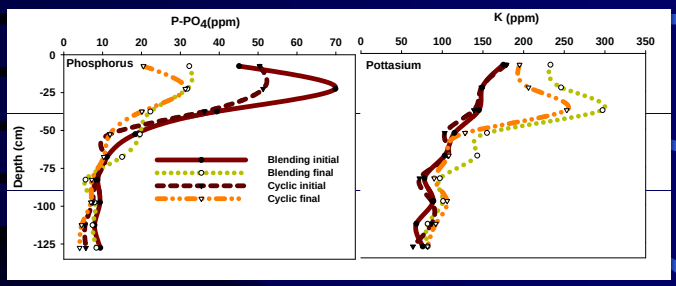


- Winter: Wastewater applied on DAP 36 (15 mm), 50 (71.7 mm), and 65 (34.5 mm).
- Summer: Time after wastewater addition (105 mm). Early times reflect transport and initial conditions, later times show retention and survival.
- Total E. coli rapidly die-off.

Conclusions

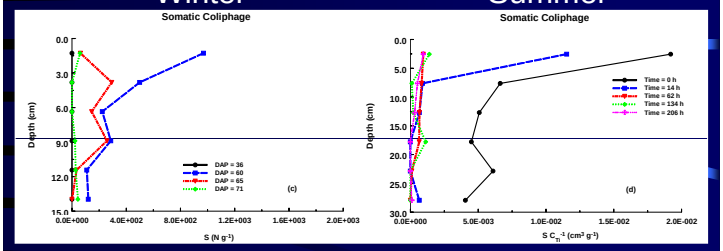
- Discussed the composition of and potential environmental contaminants in CAFO waste water.
- Land application of CAFO waste water currently needs to follow a NMP, which relies on some implicit assumptions.
- Potential contaminant loading rates and migration issues associated with NMP were discussed.
- We need to monitor the fate of CAFO contaminants at NMP sites to see if the environmental risk is acceptable.
- BMPs and treatment practices may be needed before application of CAFO wastes to NMP sites.

Phosphorus and Potassium Information



NMP Field – Somatic Coliphage

Winter Summer



- Winter: Wastewater applied on DAP 36 (15 mm), 50 (71.7 mm), and 65 (34.5 mm).
- Summer: Time after wastewater addition (105 mm). Early times reflect transport and initial conditions, later times show retention and survival.
- Somatic Coliphage rapidly die-off/inactivate.

Mineralization and Leaching of Nitrate