APPENDIX E
NITRATE SENSITIVITY ANALYSIS

Table E-1. Nitrogen Loading Analysis Before Waste Water Treatment Plant Upgrade

Site Name:	Circle WWTP, Pre-Upgrade Loading
County:	McCone
Notes:	Public, Two-celled System, constructed 1954

Effluent Seepage Rate from Pond System	**Value**	**Units**	**Notes**
Pond Seepage Discharge (Q) = KIA = 99.3 m^3/day ~ 11,601 ft^3/day	99.3	m^3/day	(3,507 ft^3/day)
Where:			
K = hydraulic conductivity of clay liner = 10^{-9} m/sec	2.34E-09	m/sec	From estimated seepage rate of 9,611,500 gal/yr (Interstate Engineering 2004)
I = Hydraulic gradient = pond operating depth+liner thickness/liner thickness =6+1 ft/1 ft	7	NA	(Interstate Engineering 2004)
A = Pond area 17.34 acres (70,173 m^2)	70173.000	m^2	(Interstate Engineering 2004)

Nitrogen Concentration of Effluent-Affected Groundwater Reaching the Redwater River				
VARIABLES	**Description**	**Value**	**Units**	**Notes**
K	Aquifer Hydraulic Conductivity	0.283	ft/day	Silty Sand at 10^{-5} cm/s (Freeze and Cherry 1979)
I	Hydraulic Gradient	0.003	ft/ft	From local wells U/S of system
D	Mixing Zone Thickness (usually constant)	15.000	ft	Assumed mixing depth in the alluvial aquifer
L	Mixing Zone Length (see ARM 17.30.517(1)(d)(viii)	300.000	ft	Measured median distance from edge of pond system to Redwater River bank
Y	Width of Source Perpendicular to Ground Water Flow	1000.000	ft	Per system plan map
Ng	Background Nitrate (as Nitrogen) Concentration in Ground Water	1.600	mg/L	Average for 53 wells "MCN" GWIC, WQ, Total Depth < 150 ft.
Nr	Nitrate (as Nitrogen) Concentration in Precipitation (usually constant)	1.000	mg/L	Default
Ne	Nitrate (as Nitrogen) Concentration in Effluent	10.600	mg/L	Circle DMR mean for TN
#l	Facility Operated as a single system discharge	1.000		
Ql	Effluent Seepage Rate	3,507	ft^3/day	
P	Precipitation	13.380	in/year	Circle weather station mean annual precipitation
V	Percent of Precipitation Recharging Ground Water (usually constant)	0.200		
EQUATIONS	**Description**	**Value**	**Units**	**Notes**
W	Width of Mixing Zone Perpendicular to Ground Water Flow = (0.175)(L)+(Y)	1052.500	ft	Assumes 5° dispersion angle from each side of the source
Am	Cross Sectional Area of Aquifer Mixing Zone = (D)(W)	15787.500	ft^2	
As	Surface Area of Mixing Zone = (L)(W)	315750.000	ft^2	

Table E-1. Nitrogen Loading Analysis Before Waste Water Treatment Plant Upgrade

Qg	Ground Water Flow Rate = (K)(I)(Am)	13.404	ft^3/day	
Qr	Precipitation Recharge Flow Rate = (As)(P/12/365)(V)	192.910	ft^3/day	
Qe	Effluent Flow Rate = (#l)(Ql)	3,507	ft^3/day	
SOLUTION	**Description**	**Value**	**Units**	**Notes**
Nt	Nitrate (as Nitrogen) Concentration entering Redwater River =((Ng)(Qg)+(Nr)(Qr)+(Ne)(Qe)) / ((Qg)+(Qr)+(Qe))	10.069	mg/L	
Surface Water-Effluent Seepage Mixing				
	Description	**Value**	**Units**	**Notes**
Nsw	Background Nitrate (as Nitrogen) Concentration in Surface Water	1.241	mg/L	Average growing season concentration for stations MCNREDW-01, MCNREDW-02 & 6177500
Qsw	Baseflow Surface Water Discharge Rate	28912.000	ft^3/day	Baseflow average (0.335 cfs)
Ngw	Concentration of Effluent-affected Groundwater	10.073	mg/L	C45Above
	Cross Sectional Area of Aquifer Mixing Zone = (D)(W)	15787.500	ft^2	C38 Above
	Aquifer Gradient	0.003	NA	C22 Above
	Aquifer Hydraulic Conductivity	0.283	ft/day	Silty Sand at 10^{-5} cm/s (Freeze and Cherry 1979)
Qgw		13.404	ft^3/day	
Qsw		28912.000	ft^3/day	
	Concentration of mixed surface water and effluent	2.527	mg/L	
Loading Contributions From Treatment System vs Upstream Sources				
	Baseflow Surface Water Discharge Rate (cfs)	0.335	cfs	Growing season baseflow average
	Upstream Nitrogen Concentration in Surface Water (mg/L)	1.241	mg/L	Mean of upstream growing season TN concentration
	Upstream Nitrogen Loading rate (lbs/day)	2.245	lbs/day	Flow (cfs)*concentration (mg/L*conversion factor (5.4)
	Effluent Discharge Rate (cfs)	0.041	cfs	C42/86400 sec/day
	Effluent Nitrogen Concentration (mg/L)	10.600	mg/L	
	Treatment System Loading Rate (lbs/day)	2.3	lbs/day	
	Treatment System Percentage of Total Load	51		
	Upstream Percentage of Nitrogen Load	49		

Table E-2. Nitrogen Loading Analysis After Waste Water Treatment Plant Upgrade

Site Name:	Circle WWTP, Post Upgrade Loading
County:	McCone
Notes:	Public, Three-celled System, constructed 2009

Effluent Seepage Rate from Pond System	**Value**	**Units**	**Notes**
Pond Seepage Discharge (Q) = KIA = 0.152 m^3/day ~ 5.4 ft^3/day	0.152	m^3/day	(5.4 ft^3/day)
Where:			
K = hydraulic conductivity of clay liner = 10^{-11} m/sec	4.600E-11	m/sec	
I = Hydraulic gradient = 1.2 m operating depth	1.200	NA	(Interstate Engineering 2004)
A = Pond area 7.9 acres (31,970 m^2)	31970.000	m^2	(Interstate Engineering 2004)

Nitrogen Concentration of Effluent-Affected Groundwater Reaching the Redwater River

VARIABLES	**Description**	**Value**	**Units**	**Notes**
K	Aquifer Hydraulic Conductivity	0.283	ft/day	Silty Sand at 10^{-5} cm/s (Freeze and Cherry 1979)
I	Hydraulic Gradient	0.003	ft/ft	From local wells U/S of system
D	Mixing Zone Thickness (usually constant)	15.000	ft	Assumed mixing depth in the alluvial aquifer
L	Mixing Zone Length (see ARM 17.30.517(1)(d)(viii)	900.000	ft	Measured median distance from edge of pond system to Redwater River bank
Y	Width of Source Perpendicular to Ground Water Flow	750.000	ft	Per system plan map
Ng	Background Nitrate (as Nitrogen) Concentration in Ground Water	1.600	mg/L	Average for 53 wells "MCN" GWIC, WQ, Total Depth < 150 ft.
Nr	Nitrate (as Nitrogen) Concentration in Precipitation (usually constant)	1.000	mg/L	Default
Ne	Nitrate (as Nitrogen) Concentration in Effluent	10.600	mg/L	Circle DMR mean for TN
#l	Facility Operated as a single system discharge	1.000		
Ql	Effluent Seepage Rate	5.385	ft^3/day	
P	Precipitation	13.380	in/year	Circle weather station mean annual precipitation
V	Percent of Precipitation Recharging Ground Water (usually constant)	0.200		
EQUATIONS	**Description**	**Value**	**Units**	**Notes**
W	Width of Mixing Zone Perpendicular to Ground Water Flow = (0.175)(L)+(Y)	907.500	ft	Assumes 5° dispersion angle from each side of the source
Am	Cross Sectional Area of Aquifer Mixing Zone = (D)(W)	13612.500	ft^2	
As	Surface Area of Mixing Zone = (L)(W)	816750.000	ft^2	
Qg	Ground Water Flow Rate = (K)(I)(Am)	11.557	ft^3/day	

Table E-2. Nitrogen Loading Analysis After Waste Water Treatment Plant Upgrade

Qr	Precipitation Recharge Flow Rate = (As)(P/12/365)(V)	499.001	ft^3/day	
Qe	Effluent Flow Rate = (1#)(Q1)	5.385	ft^3/day	
SOLUTION	**Description**	**Value**	**Units**	**Notes**
Nt	Nitrate (as Nitrogen) Concentration entering Redwater River =((Ng)(Qg)+(Nr)(Qr)+(Ne)(Qe)) / ((Qg)+(Qr)+(Qe))	1.114	mg/L	
Surface Water-Effluent Seepage Mixing				
	Description	**Value**	**Units**	**Notes**
Nsw	Background Nitrate (as Nitrogen) Concentration in Surface Water	1.231	mg/L	Mean of upstream growing season TN concentration
Qsw	Baseflow Surface Water Discharge Rate	28912.000	ft^3/day	Baseflow average-0.335 cfs
Ngw	Concentration of Effluent-affected Groundwater	1.114	mg/L	C47Above
	Cross Sectional Area of Aquifer Mixing Zone = (D)(W)	13612.500	ft^2	C37 Above
	Aquifer Gradient	0.003	NA	C19 Above
	Aquifer Hydraulic Conductivity	0.283	ft/day	Silty Sand at 10^{-5} cm/s (Freeze and Cherry 1979)
Qgw		11.557	ft^3/day	
Qsw		28912.000	ft^3/day	
	Concentration of mixed surface water and effluent	1.233	mg/L	
Loading Contributions From Treatment System vs Upstream Sources				
	Baseflow Surface Water Discharge Rate (cfs)	0.335	cfs	Growing season baseflow average
	Upstream Nitrogen Concentration in Surface Water (mg/L)	1.200	mg/L	C49 above
	Upstream Nitrogen Loading rate (lbs/day)	2.171	lbs/day	Flow (cfs)*concentration (mg/L*conversion factor (5.4)
	Effluent Discharge Rate (cfs)	0.00006	cfs	
	Effluent Nitrogen Concentration (mg/L)	10.600	mg/L	
	Treatment System Loading Rate (lbs/day)	0.004	lbs/day	
	Treatment System Percentage of Total Load	0.1641		
	Upstream Percentage of Nitrogen Load	100		

Table E-3. Nitrogen Loading Analysis Sludge Disposal Loading

Site Name:	Circle WWTP
County:	McCone
Notes:	Loading from Sludge Disposal Area of Former Two-Celled System

Effluent Seepage Rate from Sludge Disposal Area	**Value**	**Units**	**Notes**
Annual precipitation = (0.20)* (13.38) = 2.68 in/year (0.223 ft/year)	13.380	inches	Circle weather station
Sludge disposal area is 500,000 ft2	500000.000	ft^2	GIS area measurement tool
Volume of annual precipitation within disposal area	557500.000	ft^3	
Precipitation infiltration fraction	0.200		
Mean daily volume of precipitation entering local aquifer from disposal area	305.479	ft^3/day	

Nitrogen Concentration of Effluent-Affected Groundwater Reaching the Redwater River				
VARIABLES	**Description**	**Value**	**Units**	**Notes**
K	Aquifer Hydraulic Conductivity	2.830	ft/day	Silty Sand at 10-5 cm/s (Freeze and Cherry 1979)
I	Hydraulic Gradient	0.003	ft/ft	From local wells U/S of system
D	Mixing Zone Thickness (usually constant)	15.000	ft	Default
L	Mixing Zone Length (see ARM 17.30.517(1)(d)(viii)	800.000	ft	Median distance from edge of sludge disposal area to Redwater River bank
Y	Width of Drainfield Perpendicular to Ground Water Flow	1000.000	ft	Per system plan map
Ng	Background Nitrate (as Nitrogen) Concentration in Ground Water	1.600	mg/L	Average for 53 wells "MCN" GWIC, WQ, Total Depth < 150 ft.
Nr	Nitrate (as Nitrogen) Concentration in Precipitation (usually constant)	1.000	mg/L	Default
Ne	Nitrate (as Nitrogen) Concentration in Effluent	10.600	mg/L	Circle DMR mean for TN
#l	Number of Single Family Homes on the Drainfield	1.000		Source is a single system
Ql	Quantity of Affected Seepage Entering Local Groundwater	305.479	ft^3/day	Calculated for clay-lined cell
P	Precipitation	13.380	in/year	
V	Percent of Precipitation Recharging Ground Water (usually constant)	0.200		
EQUATIONS	**Description**	**Value**	**Units**	**Notes**
W	Width of Mixing Zone Perpendicular to Ground Water Flow = (0.175)(L)+(Y)	1140.000	ft	
Am	Cross Sectional Area of Aquifer Mixing Zone = (D)(W)	17100.000	ft^2	
As	Surface Area of Mixing Zone = (L)(W)	912000.000	ft^2	
Qg	Ground Water Flow Rate = (K)(I)(Am)	145.179	ft^3/day	

Table E-3. Nitrogen Loading Analysis Sludge Disposal Loading

Qr	Precipitation Recharge Flow Rate = (As)(P/12/365)(V)	557.195	ft^3/day	
Qe	Effluent Flow Rate = (#l)(Ql)	305.479	ft^3/day	
SOLUTION	**Description**	**Value**	**Units**	**Notes**
Nt	Nitrate (as Nitrogen) Concentration at end of Mixing Zone =((Ng)(Qg)+(Nr)(Qr)+(Ne)(Qe)) / ((Qg)+(Qr)+(Qe))	3.996	mg/L	
Surface Water-Effluent Mixing				
	Description	**Value**	**Units**	**Notes**
Nsw	Background Nitrate (as Nitrogen) Concentration in Surface Water	1.241	mg/L	Average growing season concentration for stations MCNREDW-01, MCNREDW-02 & 6177500
Qsw	Baseflow Surface Water Discharge Rate	28912.000	ft^3/day	Baseflow average-0.3 cfs
Ngw	Concentration of Effluent-affected Groundwater	3.996	mg/L	C41 Above
	Cross Sectional Area of Aquifer Mixing Zone = (D)(W)	17100.000	ft^2	C34 Above
	Aquifer Gradient	0.003	NA	C19 Above
	Aquifer Hydraulic Conductivity	2.830	ft/day	Silty Sand at 10-5 cm/s (Freeze and Cherry 1979)
Qgw		145.179	ft^3/day	
Qsw		28912.000	ft^3/day	
	Concentration of mixed surface water and effluent	1.353		
Loading Contributions From Treatment System vs Upstream Sources				
	Baseflow Surface Water Discharge Rate (cfs)	0.330		
	Upstream Nitrogen Concentration in Surface Water (mg/L)	1.241		
	Upstream Nitrogen Loading rate (lbs/day)	2.211		
	Effluent Discharge Rate (cfs)	0.004		
	Effluent Nitrogen Concentration (mg/L)	10.600		
	Treatment System Loading Rate (lbs/day)	0.202		
	Treatment System Percentage of Total Load	8.385		
	Upstream Percentage of Nitrogen Load	91.615		