Predictions of Groundwater Quality Improvements from Potato Process Water Reuse System Upgrades

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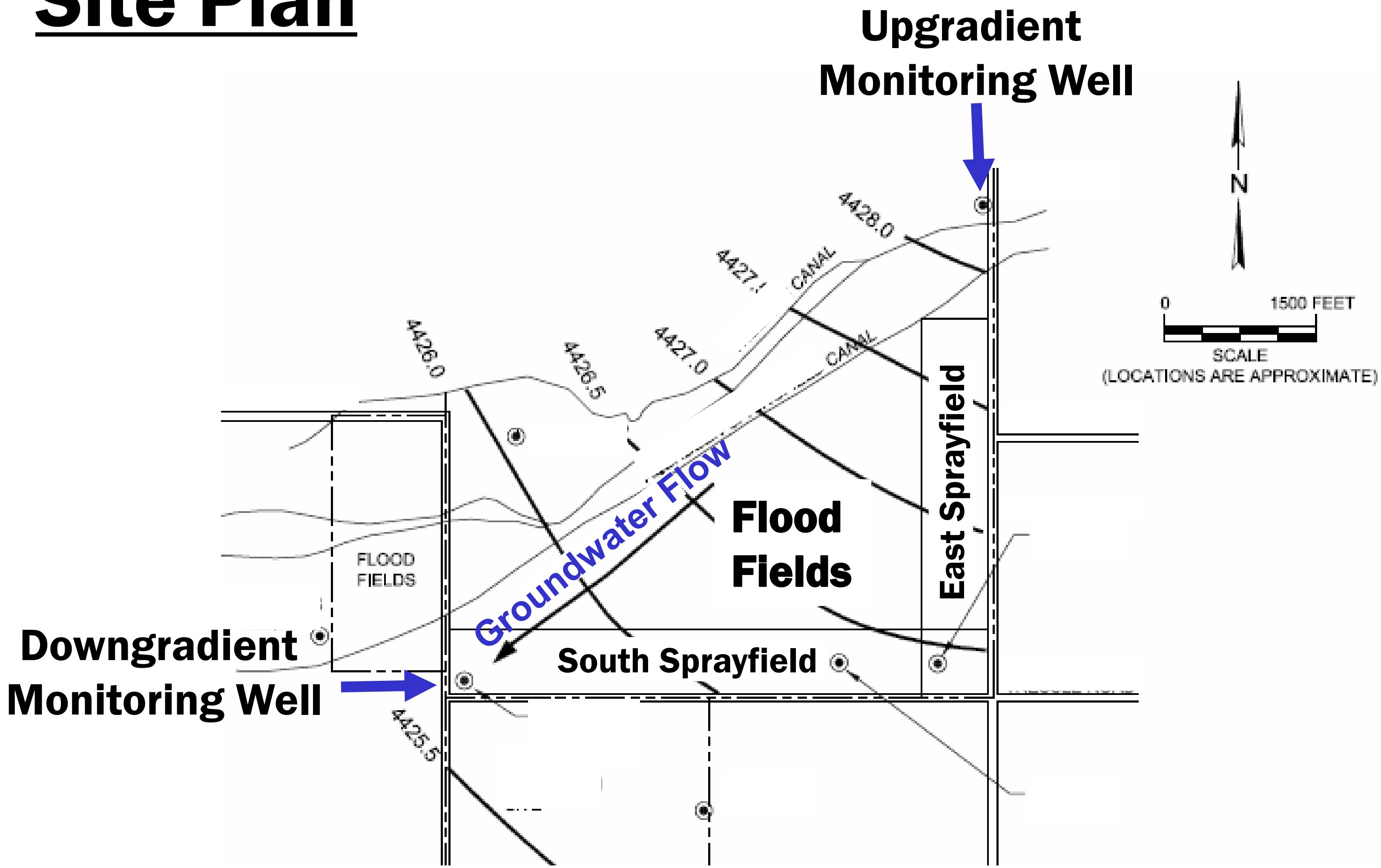
Site Plan


Upgradient
Monitoring Well
Downgradient
Monitoring Well
Groundwater Flow
Flood
Fields
East Sprayfield
South Sprayfield
FLOOD
FIELDS
CANAL
CANAL
4428.0
4427.5
4427.0
4426.5
4426.0
4425.5
N
0
1500 FEET
SCALE
(LOCATIONS ARE APPROXIMATE)

1990-1996 Groundwater Degradation

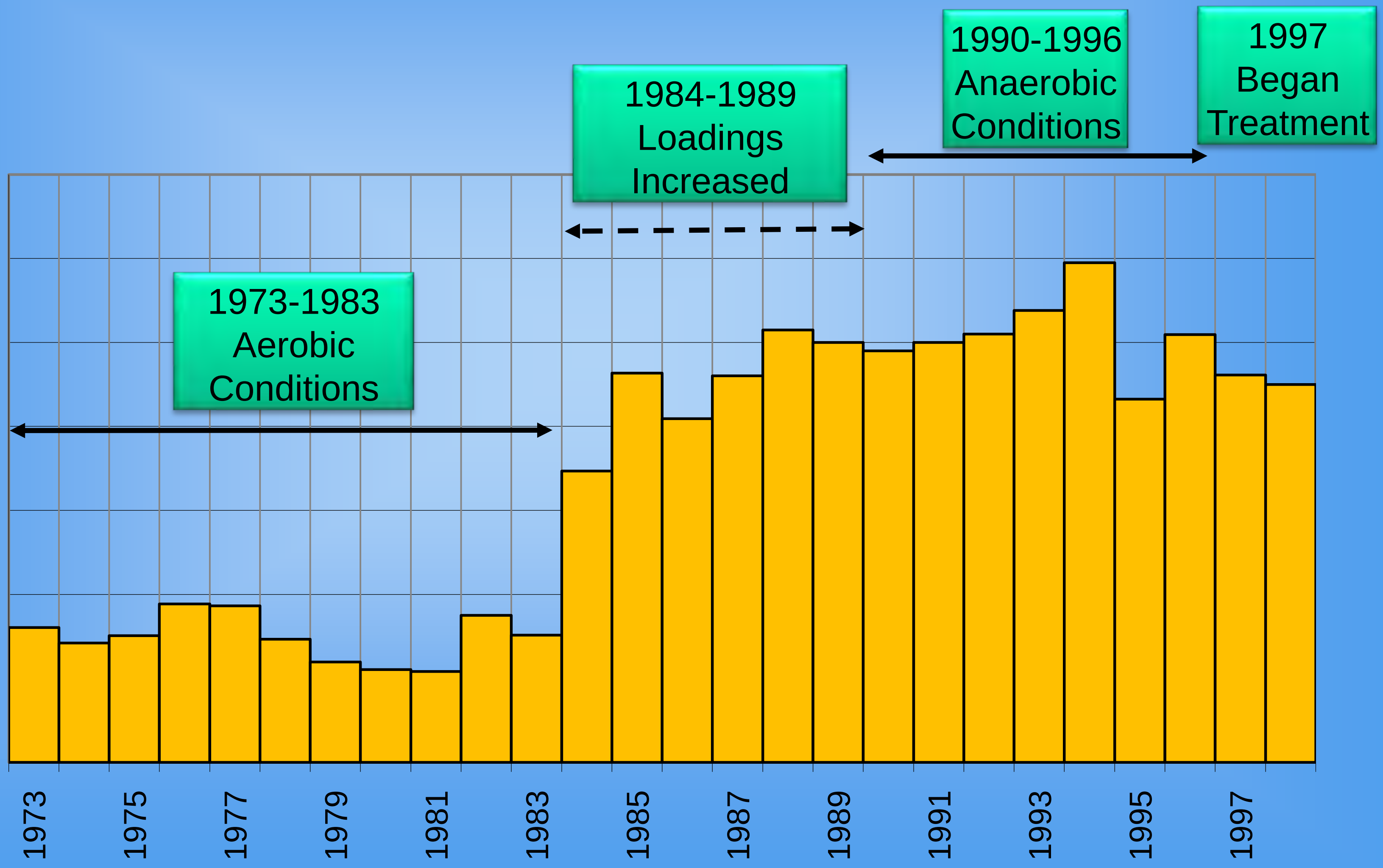
Process Water Loadings			
Hydraulic	N	COD	Inorganic TDS
Inches	Lbs/ac	Lbs/ac/d	Lbs/ac
87	1,341	91	12,250

Groundwater Quality (mg/L)				
Well Position	NO_3-N	Fe	Mn	TDS
Upgradient	1	<0.1	<0.05	264
Downgradient	<1	5-10	4-6	710

Process Water vs. Groundwater

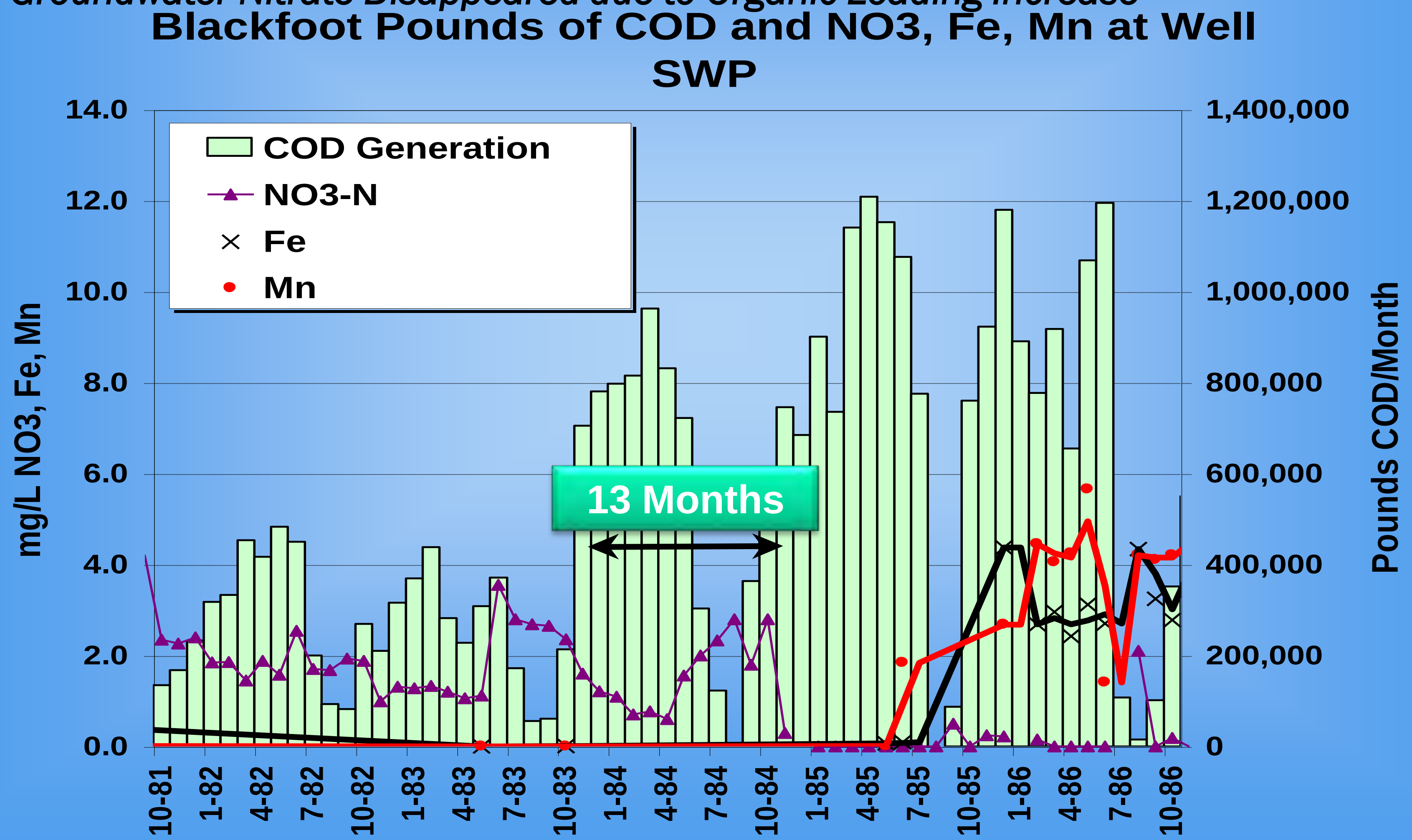
Ion	Process Water	Upgradient Groundwater	Downgradient Groundwater
	mg/L		
Ca	60	52	125
K	140	3	15
Mg	19	13	44
Na	40	12	33
50% of HCO_3	167	103	267
Cl	113	10	54
SO_4	55	28	63
PO_4	12	<1	<1
TDS	606	264	710

Annual Organic Loadings



Cause and Effects

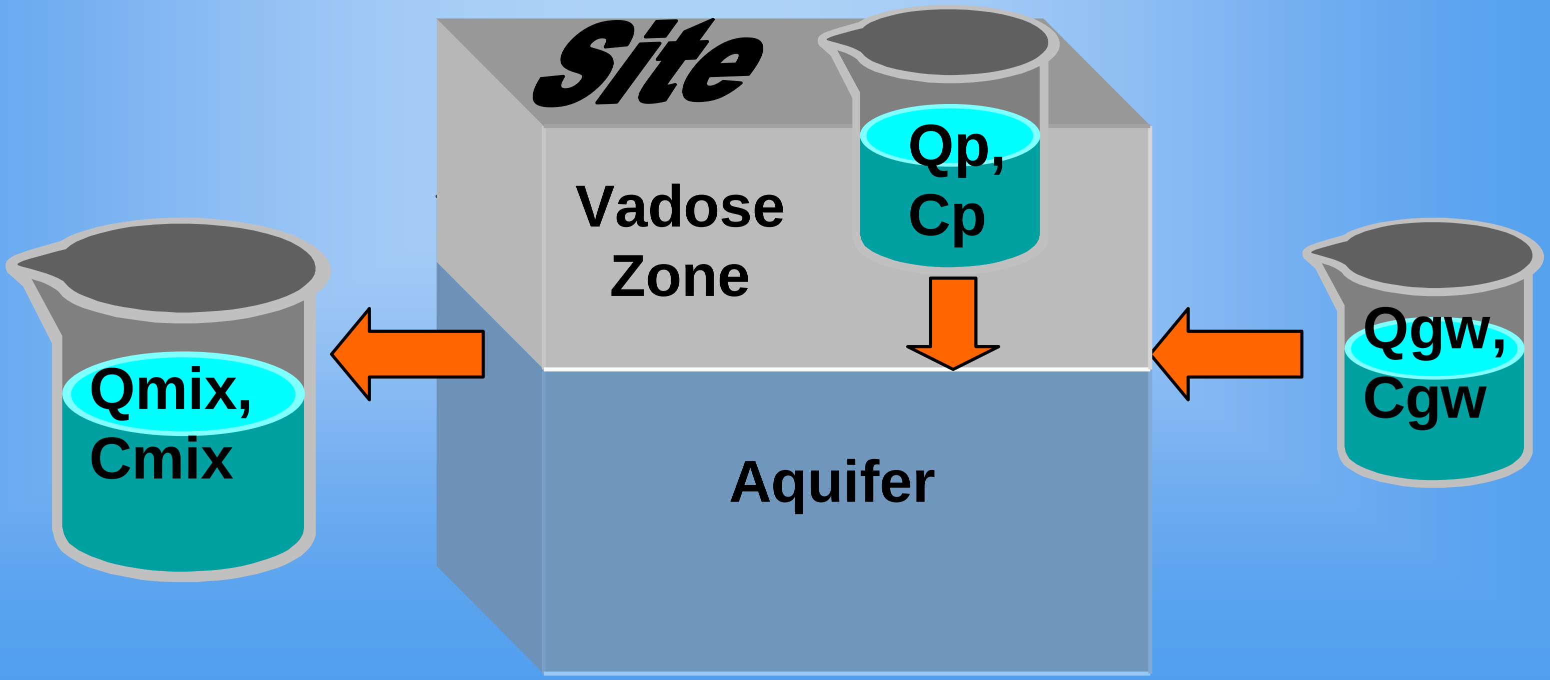
Groundwater Nitrate Disappeared due to Organic Loading Increase



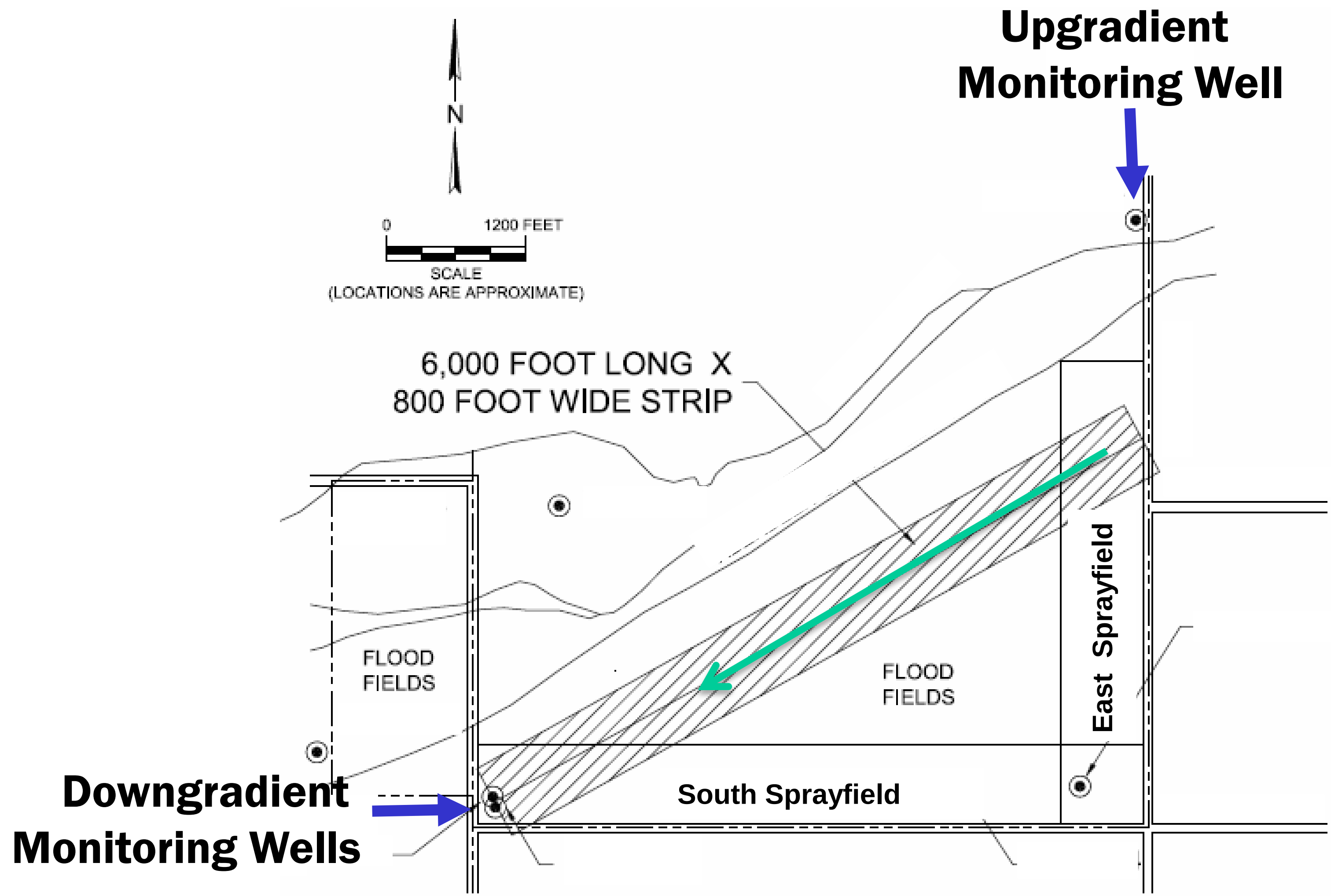
Percolate – Groundwater Mixing Model

$$Cmix = \frac{[Cgw * Qgw + Cp * Qp]}{Qmix}$$

$$Qgw = Qp \div \frac{(Cmix - Cp)}{(Cgw - Cmix)}$$



Site Layout for Mixing Model



1990-1996: Water and Chloride Balances

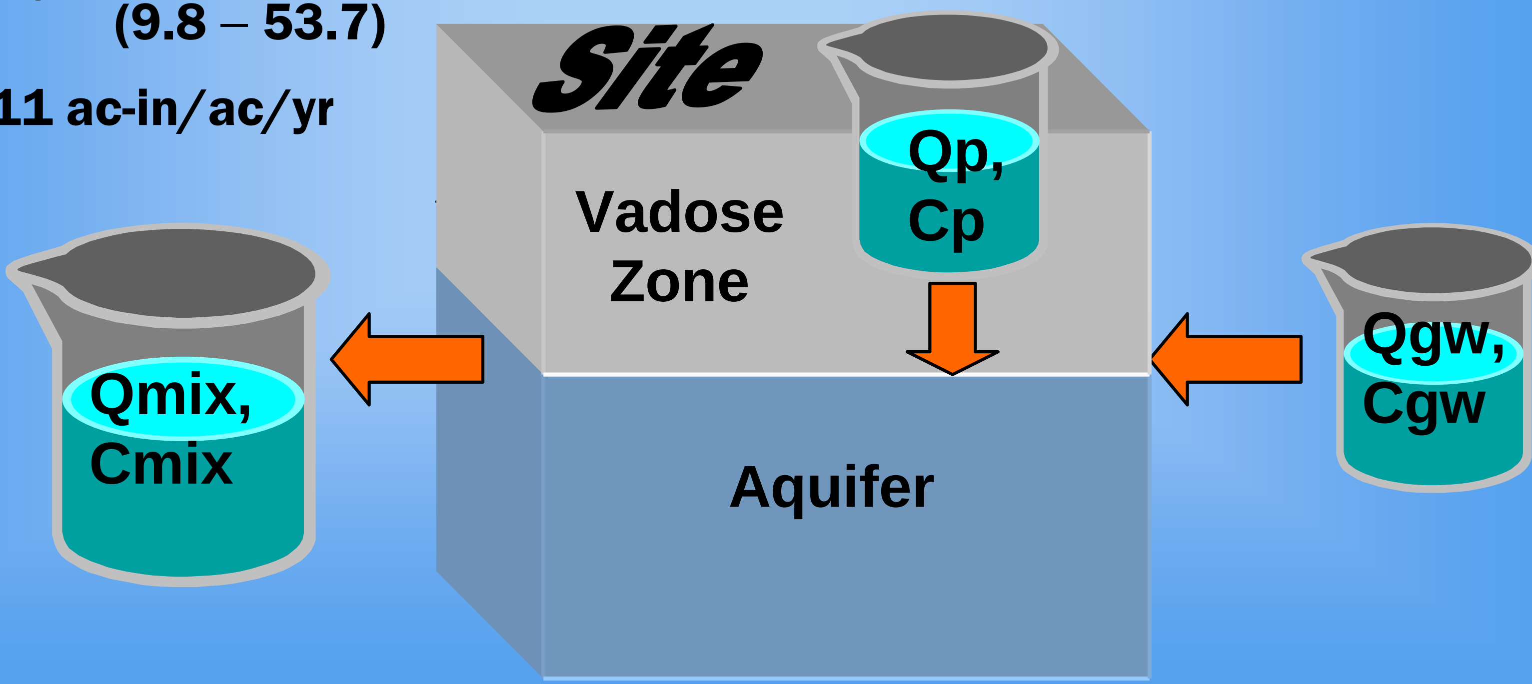
Parameters	Units	Flood Fields	Spray Fields	Combined
	acres	**85.5**	**24.9**	**110.4**
	acres	77.4%	22.6%	100%
Water Balance				
Process Water Applied	in/ac	111.3	45.8	
Canal Water Applied	in/ac	42	9	
Evaporation + Transpiration	in/ac	-26	-50	
Precipitation	in/ac	10.8	10.8	
Percolate, Qp	in/ac	138	16	**110**
Chloride Balance				
Process Water Cl concentration	mg/L	113	113	
Process Water Cl Applied	lb/ac	2,849	1,172	
Canal Cl concentration	mg/L	6.3	6.3	
Canal Water Cl Applied	lb/ac	60	13	
Crop Cl Concentration	%	1	1	
Crop Dry Matter Yield	tons/ac	3.0	6.5	
Crop Cl Removal	lb/ac	-60	-130	
Cl Mass Loss	lb/ac	2,849	1,055	**2,444**
Cl Concentration, Cp	mg/L	91	300	**98**

Use Chloride to Solve for Groundwater Flow Rate (Qgw)

$$Qgw = Qp \div \frac{(Cmix - Cp)}{(Cgw - Cmix)}$$

$$= 110 \div \frac{(53.7 - 98)}{(9.8 - 53.7)}$$

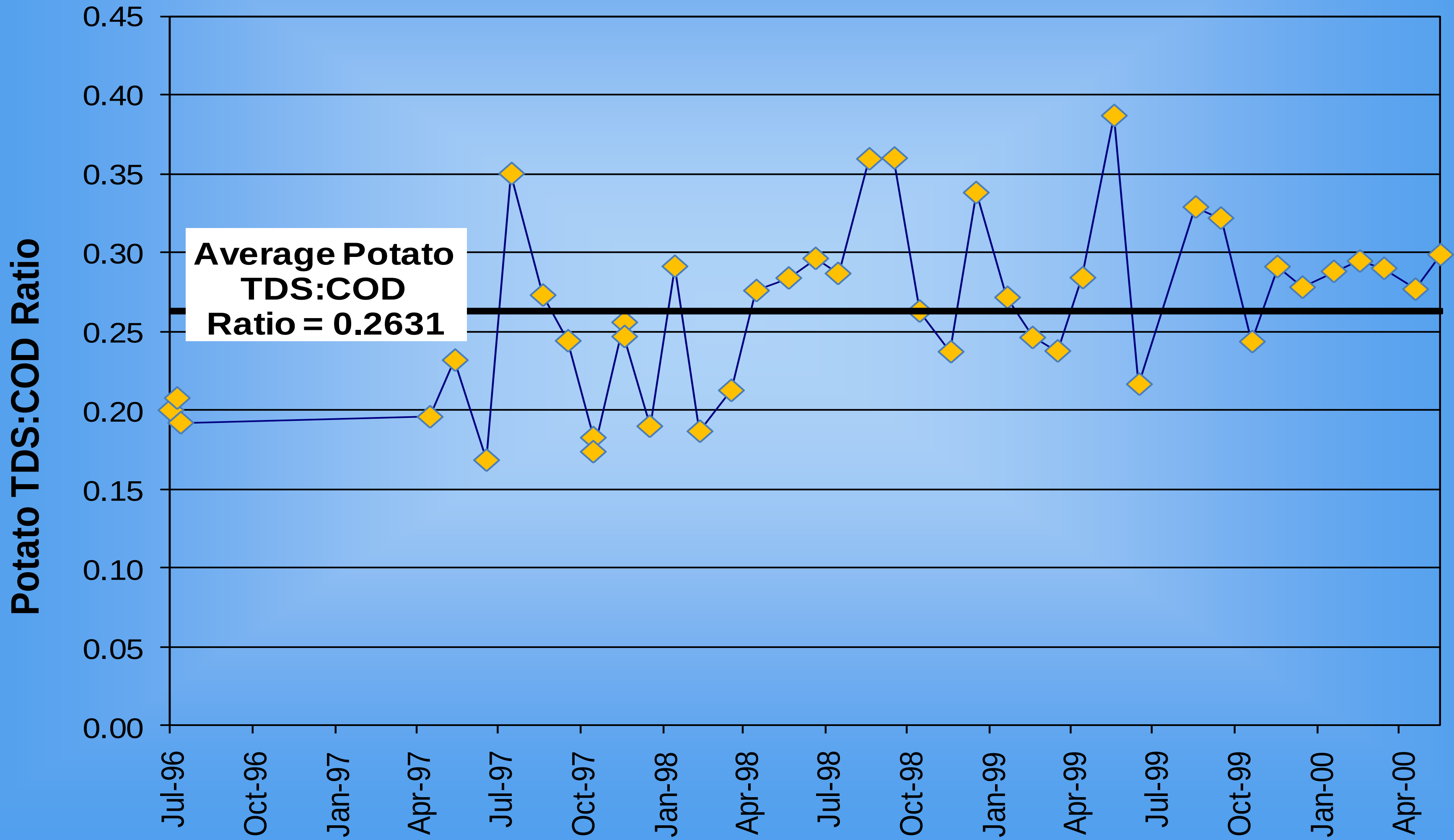
$$= 111 \text{ ac-in/ac/yr}$$



Water Supply vs. Process Water

Ion	Plant Well	Process Water
	mg/L	
Ca	59	60
K	3	140
Mg	12	19
Na	12	40
50% of HCO_3	111	167
Cl	9	113
SO_4	39	55
PO_4	<1	12
TDS	245	606

COD and Inorganic TDS from Potatoes



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1973-1983: Site Effects on Groundwater

	Process Water Loadings				Groundwater Quality			
Parameter	Hydraulic	N	COD	Inorganic TDS	NO_3-N	Fe	Mn	TDS
Units	Inches	Lbs/ac	Lbs/ac/d	Lbs/ac	mg/L			
1973-1983	65	400	27	8,050	2	<0.1	<0.05	381
1990-1996	87	1,341	91	12,250	<1	5-10	4-6	731

1973-1983: Water and TDS Balances

Parameters	Units	Center Fields	Border Fields	Combined
Area within 800 Foot Strip	acres	85.5	24.9	110.4
Percent of 800 Foot Strip	acres	77.4%	22.6%	100%
Water Balance				
Process Water Applied	in/ac	74.0	58.0	
TDS concentration	mg/L	547	547	
Canal Water Applied	in/ac	42.0	9.0	
TDS concentration	mg/L	163	163	
Evaporation + Transpiration	in/ac	-26	-26	
Precipitation	in/ac	10.8	10.8	
Percolate, Qp	in/ac	100.8	51.8	89.7
TDS Balance				
Process Water TDS Applied	lb/ac	9,168	7,186	
Canal Water TDS Applied	lb/ac	1,551	332	
Crop Salt Removal	lb/ac	-720	-720	
TDS Mass Loss	lb/ac	9,999	5,958	9,086
TDS Concentration, Cp	mg/L	438	508	447

Model Validation for 1973-1983 Period

$$C_{mix} = (C_{gw} * Q_{gw} + C_p * Q_p) \div (Q_{gw} + Q_p)$$

$$= (300 \text{ mg/L} * 111 \text{ ac-in/ac} + 447 \text{ mg/L} * 89.7 \text{ ac-in/ac}) \div (111 + 89.7 \text{ ac-in/ac})$$

$$= 365 \text{ mg/L}$$

$$C_p = C_{mix} + \frac{Q_{gw}*(C_{mix} - C_{gw})}{Q_p}$$

$$= 381 \text{ mg/L} + \frac{111 \text{ in/ac}*(381 - 300)\text{mg/L}}{89.7 \text{ in/ac}}$$

$$= 481 \text{ mg/L}$$

Possible Mass Loss = 481 mg/L * 89.7 ac-in/ac * 0.2265
= 9,773 lbs/ac/yr

Possible Unaccounted
Mass Loss = (9,773 – 9,086) lbs/ac/yr
= 687 lbs/ac/yr (8% more than Cmix estimate)

Future Water and TDS Mass Balances

Parameters	Units	Center Fields	Sprayfields	Combined
Area within 800 Foot Strip	acres	85.5	24.9	110.4
Percent of 800 Foot Strip	acres	77.4%	22.6%	100%
Water Balance				
Process Water Applied	in/ac	50.3	50.5	
TDS concentration	mg/L	505	505	
Canal Water Applied	in/ac	19.4	6.1	
TDS concentration	mg/L	163	163	
Evaporation + Transpiration	in/ac	-50.1	-50.1	
Precipitation	in/ac	10.8	10.8	
Percolate, Qp	in/ac	30.4	17.3	27.5
TDS Balance				
Process Water TDS Applied	lb/ac	5,753	5,776	5,758
Canal Water TDS Applied	lb/ac	717	225	606
Crop Salt Removal	lb/ac	-1,560	-1,560	-1,560
TDS Mass Loss	lb/ac	4,910	4,441	4,804
TDS Concentration, Cp	mg/L	713	1,133	771

Prediction of Future TDS

Cmix = (Cgw * Qgw + Cp * Qp) ÷ (Qgw + Qp)
= (264 mg/L * 111 ac-in/ac + 771 mg/L * 27.5 ac-in/ac) ÷ (111 + 27.5 ac-in/ac)
= 365 mg/L

Soil water percolation and mixing with Qgw reduced from 12 months to 9 months, so:

Qgw = 9/12 * 111 ac-in/ac/yr
= 83.3 ac-in/ac/yr

Therefore:

Cmix = (Cgw * Qgw + Cp * Qp) ÷ (Qgw + Qp)
= (264 mg/L * 83.3 ac-in/ac + 771 mg/L * 27.5 ac-in/ac) ÷ (83.3 + 27.5 ac-in/ac)
= 390 mg/L


Maximum Allowable TDS Mass Loss

$$Cp = Cmix + \frac{Qgw*(Cmix - Cgw)}{Qp}$$

$$= 500\ mg/L + \frac{83.3\ in/ac *(500 - 264)mg/L}{27.5\ ac\text{-}in/ac}$$

$$=1{,}215\ mg/L$$

Max. Allowable Mass Loss

= 1,215 mg/L * 27.5 ac-in/ac * 0.2265

= 7,568 lbs/ac/yr

Max. Allowable Process Water Application

= Max. Allowable Loss + Crop Uptake – Canal Water App.

= (7,568 + 1,560 – 606) lbs/ac/yr

= 8,522 lbs/ac/yr

Safety Factor for Proposal

= (Max. Allowable PW – Water Supply) ÷ (Proposed PW – Water Supply)

= (8,522 – 2,797) ÷ (5,758 – 2,797) lbs/ac/yr

= 1.9

Flood Irrigation Safety Factor

$$Cp = Cmix + \frac{Qgw * (Cmix - Cgw)}{Qp}$$

$$= 500\ mg/L + \frac{111\ ac\text{-}in/ac * (500 - 264) mg/L}{27.5\ ac\text{-}in/ac}$$

$$= 1{,}453\ mg/L$$

Max. Allowable Mass Loss

= 1,453 mg/L * 27.5 ac-in/ac * 0.2265

= 9,050 lbs/ac/yr

Max. Allowable PW App.

= Max. Allowable Loss + Crop Uptake – Canal Water App.

= (9,050 + 1,560 – 606) lbs/ac/yr

= 10,004 lbs/ac/yr

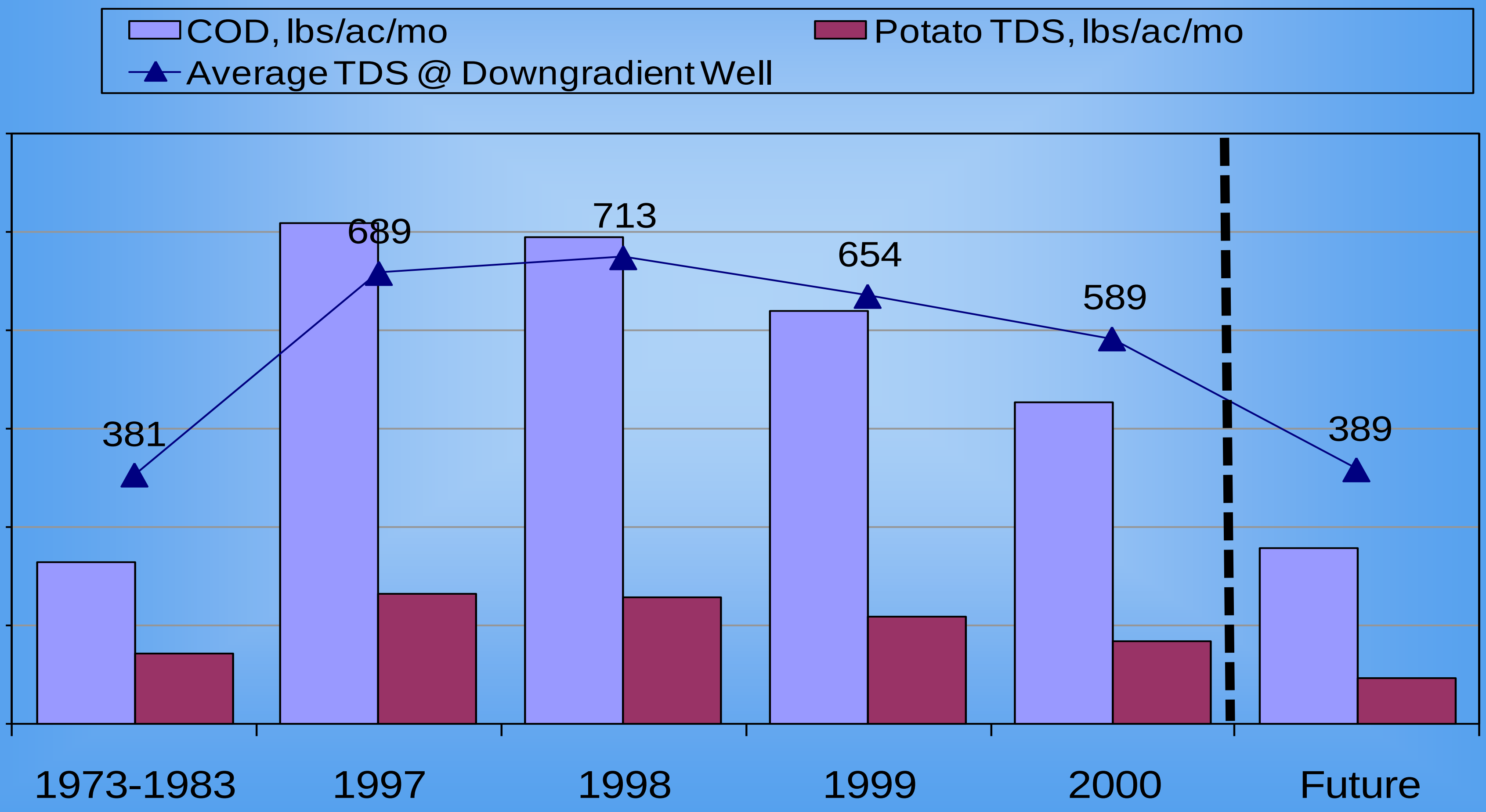
Safety Factor for Proposal

= (Max. Allowable PW – Water Supply) ÷ (Proposed PW – Water Supply)

= (10,004 – 2,797) ÷ (5,758 – 2,797) lbs/ac/yr

= 2.5 (More Water, Same Mass)

Groundwater TDS Responses to Site COD and TDS Loadings



Nitrate Analysis

Assume that no denitrification will occur.

All units are pounds per acre.

Applied	+ 450
Denitrification	0
Remaining	450
Uptake	- 383
Available to Leach	67

Cp = 67 lbs/ac/yr ÷ 27.5 in/ac/yr ÷ 0.2265
= 10.8 mg/L

Cmix = (Cgw * Qgw + Cp * Qp) ÷ (Qgw + Qp)
= (1.0 mg/L * 83.3 ac-in/ac + 10.8 mg/L * 27.5 ac-in/ac)
÷ (111 ac-in/ac)
= 3.4 mg/L


Nitrate Safety Factor

$$Cp = Cmix + \frac{Qgw(Cmix - Cgw)}{Qp}$$

$$= 10.0 \text{ mg/L} + \frac{83.3 \text{ ac-in/ac} * (10 - 1)\text{mg/L}}{27.5 \text{ ac-in/ac}}$$

$$= 37.3 \text{ mg/L}$$

Max. Annual Allowable Mass Loss

$= 27.5 \text{ ac-in/ac} * 37.3 \text{ mg/L} * 0.2265$

$= 232 \text{ lbs/ac/yr}$

Safety Factor for Proposal

= Max. Annual Mass Loss ÷ Projected Annual Mass Loss

$= 232 \text{ lbs/ac/yr} \div 67 \text{ lbs/ac/yr}$

= **3.5**

Predict Benefits of Reducing COD and TDS Loadings on Groundwater TDS

	Process Water Loadings				Groundwater Quality			
Parameter	Hydraulic	N	COD	Inorganic TDS	NO_3-N	Fe	Mn	TDS
Units	Inches	Lbs/ac	Lbs/ac/d	Lbs/ac	mg/L			
1973-1983	65	400	27	8,050	2	<0.1	<0.05	381
1990-1996	87	1,341	91	12,250	<1	5-10	4-6	731
Proposed	50	450	30	5,700	1.0-3.4	<0.1	<0.05	365-390

Summary

- Chloride can be a useful tracer (enriched in many industrial and municipal effluents, soluble, mobile)
- Long-term monitoring data is essential
- Mixing model based on steady-state conditions
  - Ideally have two time periods for validation
- Can derive groundwater flow (Qgw) from chloride model
- Groundwater flux is key to simulating future conditions