



APPENDIX B

SUPPORTING CALCULATIONS FOR DSTW AND LARGE WETLAND PILOT PROJECT CONCEPTUAL DESIGNS

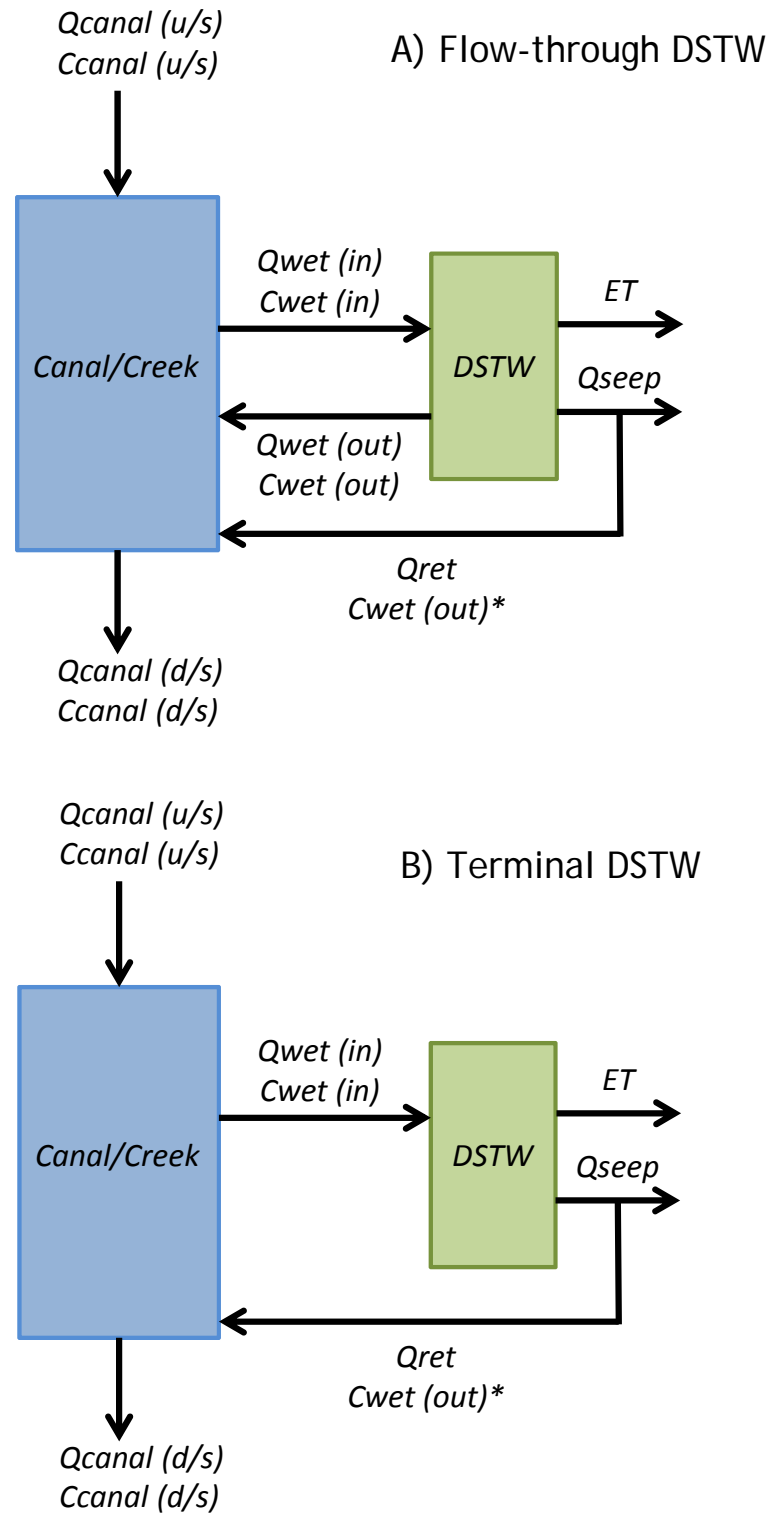


Figure B-1. Conceptual model of flows and nutrient concentrations for flow-through and terminal DSTWs in the Wood River Valley. Terms are defined on the next page.

Terms used in Figure B-1:

$Q_{\text{canal (u/s)}}$ = surface flow in the canal or creek upstream (u/s) of the DSTW

$C_{\text{canal (u/s)}}$ = concentration in the canal or creek upstream (u/s) of the DSTW

$Q_{\text{wet (in)}}$ = surface flow entering the DSTW

$C_{\text{wet (in)}}$ = concentration entering the DSTW

ET = loss of water from the DSTW due to evapotranspiration

Q_{seep} = loss of water from the DSTW to shallow groundwater

Q_{ret} = return flow from shallow ground water to canal/creek

$Q_{\text{wet(out)}}$ = surface flow leaving the DSTW and returning to the canal/creek

$C_{\text{wet (out)}}$ = concentration leaving the DSTW and returning to the canal/creek

$Q_{\text{canal (d/s)}}$ = surface flow in the canal or creek downstream (d/s) of the DSTW

$C_{\text{canal (d/s)}}$ = concentration in the canal or creek downstream (d/s) of the DSTW

*Assumes $C_{\text{wet(out)}}$ in return flow is the same as $C_{\text{wet(out)}}$ in surface flow leaving the wetland.

Table B-1. Assumptions for conceptual model of annual nutrient reduction capacity in DSTWs in the Wood River Valley. Calculations shown below are for an average DSTW area of 10 acres. Calculations were also run for an average DSTW area of 5 acres.

General	May-Oct	Nov-Apr
Average DSTW area (acres), A_{wet}	10	10
Average DSTW water depth (ft)	2	2
Average DSTW volume (acre-ft), V_{wet}	20	20
Average water temperature ($^{\circ}\text{C}$) ¹ , T	21	10
Evapotranspiration (cfs) ² , ET	0.062	0.007
Seepage return fraction ³ , $f_{seep\ ret}$	0.50	0.50
Flow and HRT in Flow-through DSTWs		
Flow in (cfs), $Q_{wet}(in)$	1	1
Seepage fraction ⁴ , f_{seep}	0.10	0.10
Seepage (cfs) ⁵ , Q_{seep}	0.100	0.100
Flow out (cfs), $Q_{wet}(out)$	0.84	0.89
Flow loss (%)	16%	11%
HRT (days) ⁶	10.1	10.1
Flow and HRT in Terminal DSTWs		
Fraction of flow-through flow (%)	0.1	0.1
Flow in (cfs), $Q_{wet}(in)$	0.1	0.1
Seepage fraction ⁴ , f_{seep}	0.9	0.9
Seepage (cfs) ⁵ , Q_{seep}	0.090	0.090
HRT (days) ⁶	21.0	21.0
Nitrate Removal		
Influent concentration (mg/L) ⁷ , $C_{wet}(in)N$	0.6	0.6
Background concentration (mg/L) ⁸ , C_b	0.015	0.015
Adjusted influent concentration (mg/L) ⁹ , $C_{wet}(in)_{adj}N$	0.585	0.585
k_{20} (m/yr) ¹⁰	44	44
Theta ¹¹ , θ	1.1	1.1
Hydraulic loading rate (m/yr) ¹² , h	22.1	22.1
Effluent concentration (mg/L) ¹³ , $C_{wet}(out)N$	0.080	0.296
Phosphorus Removal		
Influent concentration (mg/L) ⁷ , $C_{wet}(in)P$	0.3	0.3
Background concentration (mg/L) ⁸ , C_b	0.02	0.02
Adjusted influent concentration (mg/L) ⁹ , $C_{wet}(in)_{adj}P$	0.28	0.28
k_{20} (m/yr) ¹⁰	24	24
Theta ¹¹ , θ	1.00	1.00
Hydraulic loading rate (m/yr) ¹² , h	22.1	22.1
Effluent Concentration (mg/L) ¹³ , $C_{wet}(out)P$	0.114	0.114

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- ¹ Average water temperatures calculated using data from Wood River, Seven Mile Canal, and Wood River Wetland sites in Carpenter et al. (2009).
- ² Assumes evapotranspiration (ET) = 2.5 ft/yr with 90% of this occurring during May-October and 10% occurring during November-April (Bidlake 2000, Risley and Gannett 2006, Stannard et al. 2013).
- ³ Assumes a value for the fraction of groundwater seepage from wetland that returns to the canal via shallow groundwater flow. Pilot studies needed to confirm this assumption for Upper Klamath Basin.
- ⁴ Represents wetland water loss to shallow groundwater.
- ⁵ $Q_{seep} = f_{seep} \times Q_{wet(in)}$
- ⁶ Hydraulic residence time (HRT) = $V_{wet} / Q_{wet(in)}$
- ⁷ Assumes annual mean concentration at 7 Mile Dike Station for water years 2002-2010 (from Figure D5 in Walker et al. 2012). Mean concentrations at upstream locations along Sevenmile Creek/Canal can be an order of magnitude lower (Walker et al. 2012; Rick Carlson, personal communication).
- ⁸ Value for C_b is assumed. Pilot studies needed to confirm.
- ⁹ $C_{wet(in)N} = \text{Influent concentration} - C_b$
- ¹⁰ Average nitrate removal rate constant (k_{20}) for free water surface wetlands is from Table 9.40 in Kadlec and Wallace (2009). For phosphorus, overall average value is from Table 10.12 in Kadlec and Wallace (2009). Pilot studies needed to confirm this assumption for Upper Klamath Basin.
- ¹¹ Temperature coefficient for the modified Arrhenius equation; used to predict temperature effects on the first removal rate constant (k). For nitrate, assumes average value reported in Table 9.40 in Kadlec and Wallace (2009). For phosphorus, overall average value is from Table 10.12 in Kadlec and Wallace (2009). Pilot studies needed to confirm these assumptions for the Upper Klamath Basin.
- ¹² Hydraulic loading rate (h) = $Q_{wet(in)} / A_{wet}$
- ¹³ Assumes first order removal for nitrate and phosphorus. See also Eqn 6 below.

Equations used in Tables B-2 through B-5 to estimate N (as nitrate), P (as total phosphorus), and flow reductions for flow-through DSTWs:

$$C_{\text{canal}}(u/s) = C_{\text{wet}}(in) \quad (1)$$

$$Q_{\text{seep}} = f_{\text{seep}} \times Q_{\text{wet}}(in) \quad (2)$$

$$Q_{\text{wet}}(out) = Q_{\text{wet}}(in) - Q_{\text{seep}} - ET \quad (3)$$

$$Q_{\text{ret}} = f_{\text{seep ret}} \times Q_{\text{seep}} \quad (4)$$

$$Q_{\text{canal}}(d/s) = Q_{\text{canal}}(u/s) - Q_{\text{wet}}(in) + Q_{\text{wet}}(out) + Q_{\text{ret}} \quad (5)$$

$$C_{\text{wet}}(out)N = (C_{\text{wet}}(in)N - C_b)e^{-\frac{k_T}{h}\theta^{T-20}} + C_b \quad (6)$$

$$C_{\text{wet}}(out)P = (C_{\text{wet}}(in)P - C_b)e^{-\frac{k_T}{h}\theta^{T-20}} + C_b \quad (7)$$

$$C_{\text{canal}}(d/s) = \frac{Q_{\text{canal}}(u/s)C_{\text{wet}}(in) + Q_{\text{wet}}(out)C_{\text{wet}}(out) + Q_{\text{ret}}C_{\text{wet}}(out) - Q_{\text{wet}}(in)C_{\text{wet}}(in)}{Q_{\text{canal}}(d/s)} \quad (8)$$

Equations used in Tables B-2 through B-5 to estimate N (as nitrate), P (as total phosphorus), and flow reductions for terminal DSTWs:

$$C_{\text{canal}}(u/s) = C_{\text{wet}}(in) \quad (9)$$

$$Q_{\text{seep}} = f_{\text{seep}} \times Q_{\text{wet}}(in) \quad (10)$$

$$Q_{\text{ret}} = f_{\text{seep ret}} \times Q_{\text{seep}} \quad (11)$$

$$Q_{\text{canal}}(d/s) = Q_{\text{canal}}(u/s) - Q_{\text{wet}}(in) + Q_{\text{ret}} \quad (12)$$

$$C_{\text{wet}}(out)N = (C_{\text{wet}}(in)N - C_b)e^{-\frac{k_T \text{HRT}}{A_{\text{wet}}}} + C_b \quad (13)$$

$$C_{\text{wet}}(out)P = (C_{\text{wet}}(in)P - C_b)e^{-\frac{k_T \text{HRT}}{A_{\text{wet}}}} + C_b \quad (14)$$

$$C_{\text{canal}}(d/s) = \frac{Q_{\text{canal}}(u/s)C_{\text{wet}}(in) + Q_{\text{ret}}C_{\text{wet}}(out) - Q_{\text{wet}}(in)C_{\text{wet}}(in)}{Q_{\text{canal}}(d/s)} \quad (15)$$

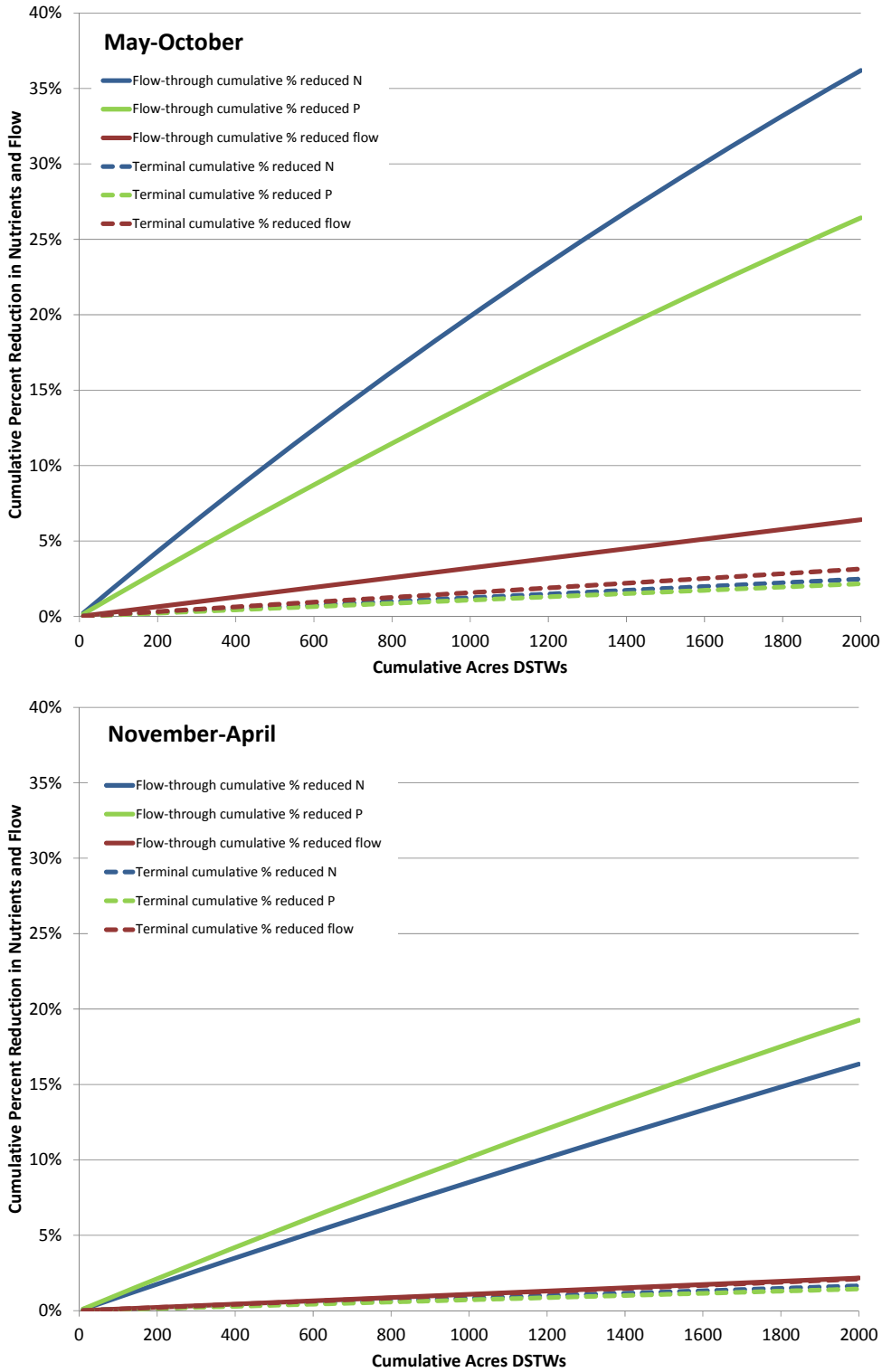


Figure B-2. Estimated cumulative percent reduction in nutrients (N as nitrate, P as total phosphorus) for conceptual arrangement of flow-through and terminal DSTWs in the Wood River Valley. The large difference in reduction capacity between flow-through and terminal DSTWs is due to the difference in flow capacity. For the conceptual estimates, flow entering the flow-through DSTWs = 1 cfs and flow entering the terminal DSTWs is 0.1 cfs.

5-acre (on average) DSTWs						
Creek/Canal-side 100% Flow-through						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	32			
Wood	Nov-Apr	400	30			
	Total	525	62	0.6%	0.8%	0.1%
Seven Mile	May-Oct	75	32			
Wood	May-Oct	275	30			
	Total	350	62	2.0%	1.1%	0.3%
Mid-field 100% Flow-through						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	148			
Wood	Nov-Apr	400	394			
	Total	525	542	5.3%	6.6%	1.1%
Seven Mile	May-Oct	75	148			
Wood	May-Oct	275	394			
	Total	350	542	16.7%	9.6%	2.5%
Total annual			604	24.7%	18.1%	4.0%
Total diversion season (May-Oct)			604	18.7%	10.7%	2.8%
10-acre (on average) DSTWs						
Creek/Canal-side 100% Flow-through						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	63			
Wood	Nov-Apr	400	115			
	Total	525	178	1.6%	1.9%	0.2%
Seven Mile	May-Oct	75	63			
Wood	May-Oct	275	115			
	Total	350	178	3.9%	2.7%	0.6%
Mid-field 100% Flow-through						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	316			
Wood	Nov-Apr	400	721			
	Total	525	1037	8.8%	10.5%	1.1%
Seven Mile	May-Oct	75	316			
Wood	May-Oct	275	721			
	Total	350	1037	20.6%	14.7%	3.3%
Total annual			1215	34.9%	29.8%	5.2%
Total diversion season (May-Oct)			1215	24.5%	17.4%	3.9%

Table B-6a. Estimated cumulative percent reduction in nutrients (N as nitrate, P as total phosphorus) for different conceptual scenarios of flow-through and terminal DSTWs in the Wood River Valley.

5-acre (on average) DSTWs						
Creek/Canal-side 100% Flow-through						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	32			
Wood	Nov-Apr	400	30			
	Total	525	62	0.6%	0.8%	0.1%
Seven Mile	May-Oct	75	32			
Wood	May-Oct	275	30			
	Total	350	62	2.0%	1.1%	0.3%
Mid-field 50/50 Flow-through/Terminal						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	148			
Wood	Nov-Apr	400	394			
	Total	525	542	3.1%	3.8%	1.1%
Seven Mile	May-Oct	75	148			
Wood	May-Oct	275	394			
	Total	350	542	9.2%	5.3%	1.8%
Total annual			604	14.9%	10.9%	3.3%
Total diversion season (May-Oct)			604	11.2%	6.4%	2.1%
10-acre (on average) DSTWs						
Creek/Canal-side 100% Flow-through						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	63			
Wood	Nov-Apr	400	115			
	Total	525	178	1.6%	1.9%	0.2%
Seven Mile	May-Oct	75	63			
Wood	May-Oct	275	115			
	Total	350	178	3.9%	2.7%	0.6%
Mid-field 50/50 Flow-through/Terminal						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	316			
Wood	Nov-Apr	400	721			
	Total	525	1037	4.9%	5.8%	1.1%
Seven Mile	May-Oct	75	316			
Wood	May-Oct	275	721			
	Total	350	1037	11.3%	8.0%	2.2%
Total annual			1215	21.7%	18.4%	4.1%
Total diversion season (May-Oct)			1215	15.1%	10.7%	2.8%

Table B-6b. Estimated cumulative percent reduction in nutrients (N as nitrate, P as total phosphorus) for different conceptual scenarios of flow-through and terminal DSTWs in the Wood River Valley.

5-acre (on average) DSTWs						
Creek/Canal-side 100% Flow-through						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	32			
Wood	Nov-Apr	400	30			
	Total	525	62	0.6%	0.8%	0.1%
Seven Mile	May-Oct	75	32			
Wood	May-Oct	275	30			
	Total	350	62	2.0%	1.1%	0.3%
Mid-field All Terminal						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	148			
Wood	Nov-Apr	400	394			
	Total	525	542	0.9%	0.8%	1.1%
Seven Mile	May-Oct	75	148			
Wood	May-Oct	275	394			
	Total	350	542	0.9%	0.8%	1.1%
Total annual			604	4.4%	3.4%	2.7%
Total diversion season (May-Oct)			604	2.9%	1.9%	1.4%
10-acre (on average) DSTWs						
Creek/Canal-side 100% Flow-through						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	63			
Wood	Nov-Apr	400	115			
	Total	525	178	1.6%	1.9%	0.2%
Seven Mile	May-Oct	75	63			
Wood	May-Oct	275	115			
	Total	350	178	3.9%	2.7%	0.6%
Mid-field All Terminal						
River	Months	Median flow (cfs) ¹	Acres ²	% N reduction ³	% P Reduction ⁴	% flow reduction ⁵
Seven Mile	Nov-Apr	125	316			
Wood	Nov-Apr	400	721			
	Total	525	1037	0.9%	0.7%	1.1%
Seven Mile	May-Oct	75	316			
Wood	May-Oct	275	721			
	Total	350	1037	0.9%	0.7%	1.1%
Total annual			1215	7.2%	6.1%	3.0%
Total diversion season (May-Oct)			1215	4.7%	3.4%	1.7%

Table B-6c. Estimated cumulative percent reduction in nutrients (N as nitrate, P as total phosphorus) for different conceptual scenarios of flow-through and terminal DSTWs in the Wood River Valley.

- ¹ From Walker et al. (2012), as cited in Stillwater Sciences et al. (2012) Table C-1.
- ² Estimated potential area for DSTWs in the Wood River Valley using generally available GIS information to consider the type, general location, and size of each wetland. No individual parcels were identified for this conceptual level analysis.
- ³ Value extracted from conceptual calculations of cumulative % nitrogen (N) reduction in Tables B-2 through B-5.
- ⁴ Value extracted from conceptual calculations of cumulative % phosphorus (P) reduction Tables B-2 through B-5.
- ⁵ Value extracted from conceptual calculations of cumulative % flow reduction Tables B-2 through B-5.

Table B-7. Assumptions for conceptual model of annual nutrient removal potential in for a 1,000-1,200-acre terraced/sloped pilot treatment and habitat wetland on the margins of Upper Klamath and Agency lakes. Calculations shown below are for an average annual inflow of 115 cfs. Calculations were also run for an average annual inflow of 45 cfs.

General	
Flow in (cfs), $Q_{wet}(in)$	115
Number cells	10
Cell length (ft)	7000
Proportional WQ treatment length ¹ , f_{treat}	0.7
Prime WQ treatment length (ft) ²	4900
Cell width (ft)	725
Cell area (ft ²)	3552500
Avg. water depth (ft)	1.75
Cell volume (ft ³), V_{cell}	6216875
Porosity	0.99
Cell HRT (days)	6
Cell Flow in (cfs), $Q_{cell}(in)$	12
Nitrate Removal (May-Oct)	
Influent concentration (mg/L) ³ , $C_{wet}(in)N$	0.6
Background concentration (mg/L) ⁴ , C_b	0.015
Adjusted influent concentration (mg/L) ⁵ , $C_{wet}(in)_{adj}N$	0.585
k_{20} (m/yr) ⁶	44
Theta ⁷ , θ	1.1
Average water temperature (°C) ⁸ , T	21
k_T (m/yr)	48
P^9	5
Hydraulic loading rate (m/yr) ¹⁰ , h	31.1
Effluent Concentration (mg/L) ¹¹ , $C_{wet}(out)N$	0.17
Reduced N (%)	72%
Phosphorus Removal (May-Oct)	
Influent concentration (mg/L) ³ , $C_{wet}(in)P$	0.3
Background concentration (mg/L) ⁴ , C_b	0.02
Adjusted influent concentration (mg/L) ⁵ , $C_{wet}(in)_{adj}P$	0.28
k_{20} (m/yr) ⁶	24
Theta ⁷ , θ	0.98
Average water temperature (°C) ⁸ , T	21
k_T (m/yr)	24
P^9	5
Hydraulic loading rate (m/yr) ¹⁰ , h	31.1
Effluent Concentration (mg/L) ¹¹ , $C_{wet}(out)P$	0.16
Reduced P (%)	47%

Table B-7 (cont). Assumptions for conceptual model of annual nutrient removal potential in for a 1,000-1,200-acre terraced/sloped pilot treatment and habitat wetland on the margins of Upper Klamath and Agency lakes.

Design Element	Treat all of Sevenmile Creek flow (115 cfs)	Treat roughly 40% of Sevenmile Creek flow (45 cfs)
Average subsidence (ft)	3	
Rough length (ft) x width (ft)	7,000 x 7,000	
Rough area (acres)	1125	
Number of treatment cells	10-15	
Proportional bench length Zone 1/2/3/4/5	0.1/0.1/0.2/0.3/0.3	
Area in treatment cells Zones 1-4 (acres)	700-800	
Area of juvenile rearing habitat Zones 1-3 (acres)	400-500	
Area in treatment cells Zone 5 (acres)	300-400	
Area of adult habitat Zones 4-5 (acres)	600-700	
Total area in treatment cells (acres)	1,000-1,200	
Area re-opened to lake (acres)	1,000-1,200	
Cell HRT (days)	6	16
Effluent Concentration (mg/L) ¹¹ , $C_{wet}(out)N$	0.17	0.05
Effluent Concentration (mg/L) ¹¹ , $C_{wet}(out)P$	0.16	0.07
Reduced N (%)	72%	92%
Reduced P (%)	47%	75%

¹ f_{treat} = fraction of total cell length that has high water treatment potential. This is mainly a function of water depth.

² Prime WQ treatment length = f_{treat} * cell length

³ Assumes annual mean concentration at 7 Mile Dike Station for water years 2002-2010 (from Figure D5 in Walker et al. 2012). Mean concentrations at upstream locations along Sevenmile Creek/Canal can be an order of magnitude lower (Walker et al. 2012; Rick Carlson, personal communication).

⁴ Value for C_b is assumed. Pilot studies needed to confirm.

⁵ $C_{wet}(in)_{adj}$ = Influent concentration - C_b

⁶ Average nitrate removal rate constant (k_{20}) for free water surface wetlands from Table 9.40 in Kadlec and Wallace (2009). For phosphorus, overall average value from Table 10.12 in Kadlec and Wallace (2009). Pilot studies needed to confirm this assumption for Upper Klamath Basin.

⁷ Temperature coefficient for the modified Arrhenius equation; used to predict temperature effects on the first removal rate constant (k). For nitrate, assumes average value reported in Table 9.40 in Kadlec and Wallace (2009). For phosphorus, overall average value is from Table 10.12 in Kadlec and Wallace (2009). Pilot studies needed to confirm these assumptions for the Upper Klamath Basin.

⁸ Average water temperatures calculated using data from Wood River, Seven Mile Canal, and Wood River Wetland sites in Carpenter et al. (2009).

⁹ P = apparent number of "tanks in series" (TIS) for the "P-k-C* Model (Kadlec and Wallace 2009). Assumed value - this may differ for the final wetland design.

¹⁰ Hydraulic loading rate (h) = $Q_{cell}(in) / A_{cell}$

¹¹ $C_{wet}(out) = [C_{wet}(in) / (1 + kT/P^*h)P] + C_b$ from "P-k-C* Model (Kadlec and Wallace 2009).