Appendices

North Fork Palouse River Dissolved Oxygen and pH Total Maximum Daily Load

Water Quality Improvement Report and Implementation Plan

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For more information contact:

Washington State Department of Ecology
Eastern Regional Office
Water Quality Program
4601 N. Monroe St.
Spokane, WA 99205-1295

Phone: 509-329-3436

Washington State Department of Ecology - www.ecy.wa.gov

- Headquarters, Olympia 360-407-6000
- Northwest Regional Office, Bellevue 425-649-7000
- Southwest Regional Office, Olympia 360-407-6300
- Central Regional Office, Yakima 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

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Appendices

North Fork Palouse River Dissolved Oxygen and pH Total Maximum Daily Load

Water Quality Improvement Report and Implementation Plan

by

Elaine Snouwaert
Water Quality Program
Eastern Regional Office

and

Tighe Stuart
Environmental Assessment Program
Eastern Regional Office

Washington State Department of Ecology
Eastern Regional Office
4601 N. Monroe St.
Spokane, Washington 99205-1295

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Appendix A. Data Summary

Continuous temperature data, time-of-travel data, and flow measurements taken as part of temperature monitoring are summarized in the Palouse River Temperature Total Maximum Daily Load report (Snouwaert and Stuart, 2013). Biweekly flow measurements at 34PAL91.5 are summarized in the Palouse River Fecal Coliform Total Maximum Daily Load report (Tarbutton et al., 2010).

This appendix summarizes the data that were collected specifically for the North Fork dissolved oxygen and pH TMDL, including two synoptic surveys and a periphyton survey in 2007, and a supplemental continuous hydrolab survey in 2012.

Sample Locations

Table A-1. Sampling locations used during the North Fork Palouse River DO-pH TMDL study.

Location ID	Location Description	2007				2012	Latitude	Longitude
		Nutrients / Field Measurements	Periphyton/ Macrophytes	Continuous Temp	Continuous Hydrolab	Continuous Hydrolab		
34PAL124.3	Palouse River at State Line	X	X	X	X	X	46.9123	-117.0382
34PAL122.2	Palouse River nr Loop Rd.					X	46.9082	-117.0573
34PAL120.8	Palouse River at S. River Rd.					X	46.9101	-117.0686
34PAL120.3	Palouse River at Bridge St.	X	X	X	X	X	46.9090	-117.0760
34PAL120.0	Palouse River at Main St.					X	46.9087	-117.0831
34PAL118.9	Palouse River at Hwy 272	X	X	X	X	X	46.9145	-117.0853
34PAL116.8	Palouse River at Duffield Ck.					X	46.9301	-117.0915
34PAL112.4	Palouse River at Altergott Rd.	X	X	X	X	X	46.9471	-117.1455
34PAL103.9	Palouse River at Elberton	X	X	X	X		46.9818	-117.2201
34PAL98.3	Palouse River at Glenwood	X		X	X		46.9302	-117.2851
34PAL91.7	Palouse River above Colfax	X			X[1]		46.9076	-117.3381
34PAL91.5	Palouse River above SF Palouse confluence	X	X	X	X		46.8897	-117.3659
34SIL00.0	Silver Creek at mouth	X		X	X		46.9820	-117.2202
34PALWWTP	Palouse Wastewater Treatment Plant effluent	X		X	X		46.9087	-117.0830

[1] Continuous Hydrolab data was collected at 34PAL91.7 during the August synoptic survey but not during the July one.

Laboratory Data

Table A-2. Abbreviations and units of measurement used in this section.

Abbreviation	Parameter	Unit of Measurement
Alk	Alkalinity, Total as $CaCO_3$	mg/L
Cl	Chloride	mg/L
NH_4	Ammonia Nitrogen	mg/L
NO_2-NO_3	Nitrite-Nitrate Nitrogen	mg/L
TPN	Total Persulfate Nitrogen	mg/L
OP	Orthophosphate	mg/L
TP	Total Phosphorus	mg/L
DOC	Dissolved Organic Carbon	mg/L
TOC	Total Organic Carbon	mg/L
TSS	Total Suspended Solids	mg/L
TNVSS	Total Non-volatile Suspended Solids	mg/L
Turb	Turbidity	NTU
Chl a	Chlorophyll a	ug/L

Table A-3. Data qualifiers used in this section.

Qualifier	Meaning
U	The analyte was not detected at or above the reported result.
J	The analyte was positively identified. The associated numerical result is an estimate.

Table A-4. Laboratory water quality results from the North Fork Palouse River DO-pH TMDL study.

Location ID	Date	Time	Alk	Cl	NH_4	NO_2-NO_3	TPN	OP	TP	DOC	TOC	TSS	TNVSS	Turb	Chl a
34PAL124.3	7/30/2007	10:10:00	39	1.92	0.01 U	0.01 U	0.265	0.017 J	0.0336	4	4.7	3	1 U	2.1	1.8 J
34PAL124.3	7/30/2007	10:10:00	39	1.99	0.01 U	0.01 U	0.26	0.017 J	0.0333	3.8	4.7	2	2 U	2.1	2.1 J
34PAL124.3	7/30/2007	13:35:00	38	1.9	0.01 U	0.01 U	0.272	0.014 J	0.0304	4	4.5				
34PAL124.3	8/27/2007	9:30:00	46	2.89	0.01 U	0.01 U	0.299	0.0076	0.0276	4.2	4.9				
34PAL124.3	8/27/2007	9:30:00	46	2.92	0.01 U	0.01 U	0.273	0.0075	0.0271	4.6	4.8				
34PAL124.3	8/27/2007	13:40:00	46	2.93	0.01 U	0.01 U	0.305	0.0074	0.0288	4.2	5.1	1 U	1 U	1.3	1
34PAL120.3	7/30/2007	11:20:00	38	1.83	0.01 U	0.01 U	0.319	0.014 J	0.0288	4.4	4.8	3	2 U	1.9	1.2 J
34PAL120.3	7/30/2007	14:25:00	38	1.87	0.01 U	0.01 U	0.333	0.014	0.0325	4.4	5				
34PAL120.3	8/27/2007	11:10:00	47	2.76	0.01 U	0.01 U	0.354	0.0056	0.0294	4.4	5.3				
34PAL120.3	8/27/2007	14:30:00	47	2.84	0.01 U	0.01 U	0.361	0.0056	0.0234	4.5	5.4	2	1	2.1	0.87
34PAL118.9	8/27/2007	11:50:00	57.4	6.13	0.01 U	0.635	1.06	0.0869	0.119	4.7	5.4				
34PAL118.9	8/27/2007	15:00:00	55.1	5.7	0.01 U	0.424	0.818	0.0795	0.114	4.5	5.5	1	1 U	1.3	8.5
34PAL112.4	7/30/2007	11:55:00	49	3.34	0.01 U	0.01 U	0.345	0.0379 J	0.0583	4.5	5.4	2	2	1.8	2.2 J
34PAL112.4	7/30/2007	15:15:00	47	3.49	0.01 U	0.01 U	0.391	0.046	0.0667	4.2	5.2				
34PAL112.4	7/30/2007	15:15:00	47	3.43	0.01 U	0.01 U	0.338	0.0459	0.0679	4.1	5.3				
34PAL112.4	8/27/2007	12:40:00	63.3	4.71	0.01 U	0.01 U	0.392	0.011	0.0313	4.6	5.9				
34PAL112.4	8/27/2007	15:45:00	65.6	4.49	0.01 U	0.01 U	0.39	0.015	0.0354	4.9	5.4	1 U	1 U	1.1	1.6
34PAL112.4	8/27/2007	15:45:00	64.5	4.48	0.01 U	0.01 U	0.359	0.015	0.0333	4.5	5.6	1	1 U	1.3	1.7
34PAL103.9	7/30/2007	12:30:00	54.2	2.93	0.01 U	0.01 U	0.338	0.013 J	0.0259	4.6	5.5	2 U	1	1.3	2.7 J
34PAL103.9	7/30/2007	16:05:00	50.7	2.99	0.01 U	0.01 U	0.413	0.016	0.0336	4.8	5.8				
34PAL103.9	8/27/2007	13:15:00	70.7	5.94	0.01 U	0.01 U	0.472	0.003 U	0.015	5.2	6				
34PAL103.9	8/27/2007	16:20:00	68	6.02	0.01 U	0.01 U	0.421	0.0033	0.0196	5.4	6.1	2 U	1	1	2.4
34PAL98.3	7/30/2007	11:10:00	63.7	2.8	0.01 U	0.01 U	0.403	0.014 J	0.0258	5.6	6	2	2	2.2	3.4 J
34PAL98.3	7/30/2007	15:00:00	60.5	2.76	0.025	0.01 U	0.589	0.018	0.0424	5.8	6.5				
34PAL98.3	8/27/2007	10:20:00	82.7	5.14	0.01 U	0.01 U	0.434	0.003 U	0.0172	5.5	6.4				
34PAL98.3	8/27/2007	14:20:00	79.2	5.11	0.01 U	0.01 U	0.453	0.004	0.0163	5.1	6.1	2	2 U	1.6	3.4
34PAL91.7	8/27/2007	9:20:00	82.7	4.75	0.01 U	0.01 U	0.466	0.003 U	0.0181	5.6	6.7				
34PAL91.7	8/27/2007	15:10:00	80.3	4.82	0.01 U	0.01 U	0.496	0.0032	0.0208	5.7	6.5	2	2 U	1.7	4
34PAL91.5	7/30/2007	11:45:00	71.4	4.87	0.029	0.078	0.572	0.026 J	0.049	5.6	6.2	7	6	4.4	5.1 J
34PAL91.5	7/30/2007	15:30:00	70.6	4.8	0.025	0.071	0.561	0.027	0.051	5.5	6.2				
34PAL91.5	7/31/2007	8:30:00	72.3	4.85	0.032	0.087	0.609	0.023 J	0.0494	5.3	6.3	6	5	4.5	4.9
34PAL91.5	7/31/2007	13:45:00	71.1	4.64	0.02	0.071	0.609	0.023	0.0484	5.5	6.4				
34PAL91.5	7/31/2007	13:45:00	70.7	4.72	0.017	0.07	0.585	0.024	0.0488	5.4	6.5				

Location ID	Date	Time	Alk	Cl	NH_4	NO_2-NO_3	TPN	OP	TP	DOC	TOC	TSS	TNVSS	Turb	Chl a
34PAL91.5	8/27/2007	10:55:00	84	5	0.015	0.038	0.541	0.0096	0.0337	5.8	6.7				
34PAL91.5	8/27/2007	15:00:00	82.5	4.95	0.021	0.034	0.554	0.012	0.0362	5.9	6.7	11	9	7.3	5.7
34PAL91.5	8/27/2007	15:00:00	81.9	4.94	0.03	0.034	0.559	0.012	0.0364	5.9	7	10	7	6.8	5.5
34PAL91.5	8/28/2007	8:40:00	84.3	5.17	0.024	0.041	0.552	0.0096	0.0302	5.8	6.7				
34PAL91.5	8/28/2007	12:35:00	82.7	5.32	0.024	0.042	0.558	0.011	0.0297	5.7	6.5	6	5	5.6	4.4
34SIL00.0	7/30/2007	9:50:00	142	2.3	0.01 U	0.043	0.19	0.139 J	0.177	1.5	2	10	10	5.2	3.2 J
34SIL00.0	7/30/2007	14:10:00	142	2.29	0.011	0.04	0.17	0.143 J	0.182	1.8	2.5				
34SIL00.0	8/27/2007	9:30:00	141	2.43	0.012	0.032	0.15	0.104	0.144	1.3	2				
34SIL00.0	8/27/2007	13:45:00	141	2.48	0.01 U	0.029	0.15	0.105	0.139	1.3	1.9	6	4	3.8	7.5
34PALWTP	7/30/2007	10:40:00	96.7	73.9	0.062	30.8	34	6.13 J	7.05	6.6	7.3	1 U	1 U	0.6	0.68 J
34PALWTP	7/30/2007	10:50:00	96.6	73.8	0.058	33.1	32.6	6.18	7.16	6.8		2	1 U	1.1	1.1 J
34PALWTP	7/30/2007	14:30:00	96.7	74.2	0.048	30	34.1	6.12 J	7.13	6.8	7.4				0.83 J
34PALWTP*	7/31/2007	12:10:00	97.5	73.6	0.05	31.1	36.6	6.17 J	7.35	7.1	7	1 U	1 U	0.7	0.27 J
34PALWTP*	7/31/2007	12:10:00	98.2	74.2	0.051	33.4	32.3	6.06 J	7.34	7	7	1	1 U	0.8	0.28 J
34PALWTP	8/27/2007	10:45:00	97.9	85.3	0.161	30.6	32	5.74	6.1	6.8	7.6	2	1 U	1.6	0.56
34PALWTP	8/27/2007	11:05:00	98	86.3	0.144	31.9	32	5.84	6.17	6.9	7.7	3	1 U	2.1	0.77
34PALWTP	8/27/2007	14:30:00	96.9	85.4	0.052	36.8	32.3	5.8	6.09	7	7.7	3	1 U	2.1	15.2
34PALWTP*	8/28/2007	12:00:00	97.5	84	0.068	32.7	31.9	5.76	6.03	7	7.7	3	1 U	2.3	1.9
34PALWTP*	8/28/2007	12:00:00	97.5	83.8	0.067	32.5	31.8	5.22	5.78	7	7.3	3	1 U	2.5	1.4

*24-hr composite samples

Field Water Quality Measurement Data

Table A-5. Abbreviations and units of measurement used in this section.

Abbreviation	Parameter	Unit of Measurement
Temp	Stream Temperature	°C
Cond	Specific Conductivity	uS/cm
pH	pH	S.U.
DO	Dissolved Oxygen (Hydrolab® probe)[1]	mg/L
Wink	Dissolved Oxygen (Winkler titration)	mg/L

[1]All DO data taken using Hydrolab® probes are corrected using Winkler titration data.

Table A-6. Field water quality measurements taken during the North Fork Palouse River DO-pH TMDL study.

Location ID	Date	Time	Temp	Cond	pH	DO	Wink
34PAL124.3	7/30/2007	10:10					5.5
34PAL124.3	7/30/2007	13:35					8.65
34PAL124.3	8/27/2007	9:30	16.06	102	7.74	7.33	7.55
34PAL124.3	8/27/2007	13:40	18.62	101	8.25	8.86	10.35
34PAL120.3	8/27/2007	11:10	16.57	105	8.95	8.74	
34PAL120.3	8/27/2007	14:30	19.00	106	8.82	8.96	
34PAL118.9	8/27/2007	11:50	16.04	143	9.07	9.67	
34PAL118.9	8/27/2007	15:00	18.93	140	9.58	13.07 J	
34PAL112.4	8/27/2007	12:40	16.88	136	8.52	10.98	
34PAL112.4	8/27/2007	15:45	19.67	141	8.71	9.60	10.62
34PAL103.9	7/30/2007	12:30					12.2
34PAL103.9	7/30/2007	16:05					11.61
34PAL103.9	8/27/2007	13:15	21.14	158 J	9.64	12.96	
34PAL103.9	8/27/2007	16:20	22.02	156 J	9.76	12.20	12.28
34PAL98.3	8/27/2007	10:20	16.44	173 J	8.89	10.28	
34PAL98.3	8/27/2007	14:20	21.85	168 J	9.52	10.31	
34PAL91.7	8/27/2007	9:30	15.7	163	8.29	10.81	10.80
34PAL91.7	8/27/2007	14:50	22.2	164	8.89	11.42	
34PAL91.5	7/31/2007	8:30	21.05	160	8.01	6.72	
34PAL91.5	7/31/2007	13:45	24.48	158	8.48	8.19	8.70
34PAL91.5	8/27/2007	10:55	18.30	176 J	8.44	8.49	
34PAL91.5	8/27/2007	15:00	19.96	174 J	8.89	9.32	
34PAL91.5	8/28/2007	8:40	16.70	180	8.39	9.07	
34PAL91.5	8/28/2007	12:35	19.49	179	8.54	9.95	
34SIL00.0	8/27/2007	9:30	11.44	265	8.14	9.54	10.66
34SIL00.0	8/27/2007	13:45	14.26	265	8.49	10.46	
34PALWTP	7/30/2007	10:40	23.20	654	6.99		5.5
34PALWTP	7/30/2007	10:50	23.40	680	7.29		6
34PALWTP	7/30/2007	14:30	24.07	696	7.24	5.92	
34PALWTP	7/31/2007	12:10	23.80	671	7.39		6.6
34PALWTP	8/27/2007	10:45	20.00	784	7.24		6.35
34PALWTP	8/27/2007	11:05	20.10	783	7.06		6.12
34PALWTP	8/27/2007	14:30	20.80	783	7.22		6.45
34PALWTP	8/28/2007	12:00	20.80	780	7.42		6.21

Flow Measurement Data

Table A-7. Abbreviations and units of measurement used in this section.

Abbreviation	Parameter	Unit of Measurement
Flow	Streamflow	cfs
Dep	Average Depth	ft
Vel	Average Velocity	ft/s
WW	Wetted Width	ft

Table A-8. Flow measurements taken during the North Fork Palouse River DO-pH TMDL study.

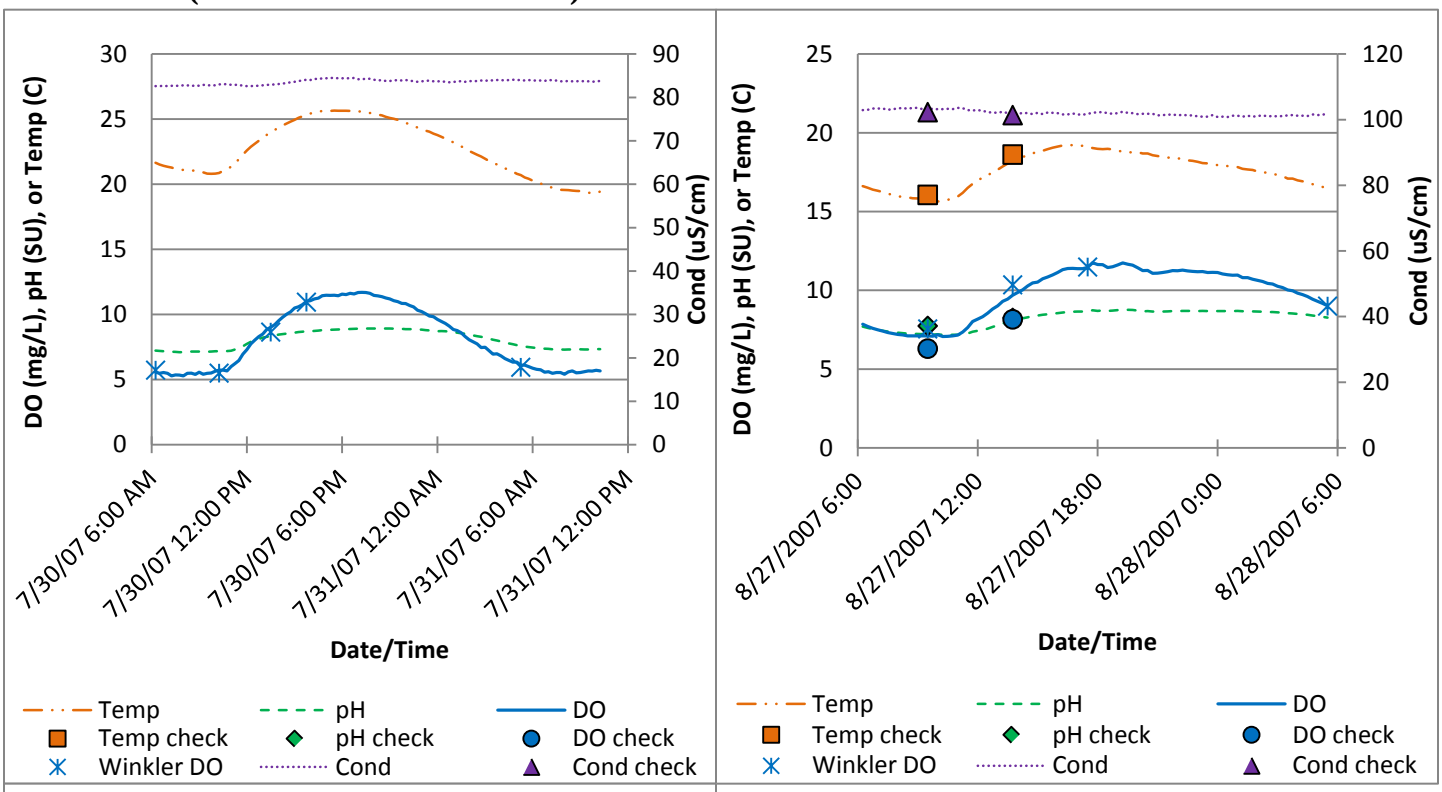
Site	Date	Time	Flow	Dep	Vel	WW
34PAL124.3	7/30/07	10:10	8.2	2.08	0.06	62.9
34PAL124.3	7/30/07	10:35	6.8	2.07	0.05	62.9
34PAL124.3	7/30/07	13:35	5.9	2.05	0.05	63.0
34PAL124.3	8/27/07	9:30	2.2	2.17	0.02	63.8
34PAL124.3	8/27/07	10:15	1.9	2.17	0.01	63.8
34PAL124.3	8/27/07	13:40	2.2	2.23	0.02	63.5
34PAL120.3	7/30/07	11:20	5.1	0.82	0.10	61.5
34PAL120.3	7/30/07	14:25	6.2	0.88	0.12	61.5
34PAL120.3	8/27/07	11:10	3.3	0.95	0.06	62.0
34PAL120.3	8/27/07	14:30	2.5	0.95	0.04	61.8
34PAL118.9	8/27/07	11:50	3.1	1.99	0.03	53.3
34PAL118.9	8/27/07	15:00	3.6	2.00	0.03	53.4
34PAL112.4	7/30/07	11:55	6.1	0.75	0.15	52.0
34PAL112.4	7/30/07	15:15	5.5	0.75	0.14	51.0
34PAL112.4	7/30/07	15:30	5.4	0.75	0.14	51.0
34PAL112.4	8/27/07	12:40	3.9	0.84	0.09	52.0
34PAL112.4	8/27/07	15:45	3.5	0.81	0.08	51.9
34PAL112.4	8/27/07	16:15	3.6	0.81	0.08	51.9
34PAL103.9	7/30/07	12:30	4.6	0.54	0.17	49.4
34PAL103.9	7/30/07	16:05	4.3	0.49	0.18	49.1
34PAL103.9	8/27/07	13:15	3.7	0.56	0.13	49.7
34PAL103.9	8/27/07	16:20	3.5	0.55	0.13	49.7
34PAL98.3	7/30/07	11:10	4.2	0.57	0.24	31.4
34PAL98.3	7/30/07	15:00	4.5	0.67	0.20	32.9
34PAL98.3	8/27/07	10:20	4.9	0.63	0.25	31.4
34PAL98.3	8/27/07	14:20	3.6	0.61	0.18	32.5
34PAL91.7	8/27/07	9:30	3.7	0.73	0.11	44.4
34PAL91.7	8/27/07	14:50	4.0	0.71	0.13	45.3
34PAL91.5	7/30/07	11:45	4.0	0.47	0.35	24.4
34PAL91.5	7/30/07	15:30	3.3	0.46	0.30	24.3
34PAL91.5	7/31/07	8:30	3.6	0.47	0.30	25.1
34PAL91.5	7/31/07	13:45	3.4	0.49	0.28	24.8
34PAL91.5	7/31/07	14:05	3.4	0.49	0.28	24.8
34PAL91.5	8/27/07	10:55	3.9	0.54	0.29	25.0
34PAL91.5	8/27/07	15:00	3.7	0.52	0.28	25.1
34PAL91.5	8/27/07	15:10	3.8	0.53	0.29	25.1
34PAL91.5	8/28/07	8:40	4.2	0.52	0.34	24.0
34PAL91.5	8/28/07	12:35	4.4	0.54	0.33	24.6
34SIL00.1	7/30/07	9:50	0.42	0.30	0.23	6.0
34SIL00.1	7/30/07	14:10	0.36	0.41	0.15	5.6
34SIL00.1	8/27/07	9:30	0.49	0.41	0.21	5.8
34SIL00.1	8/27/07	13:45	0.44	0.45	0.17	5.7

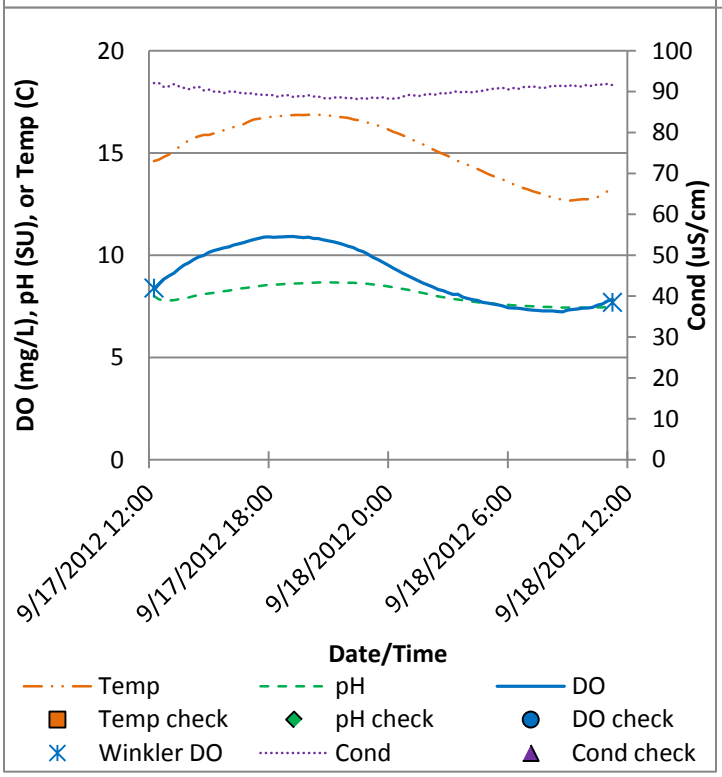
Continuous Measurement Data

Figure A-1. Plots of continuous dissolved oxygen, pH, conductivity, and temperature data collected on the North Fork Palouse River *(this page plus the following 7 pages).*

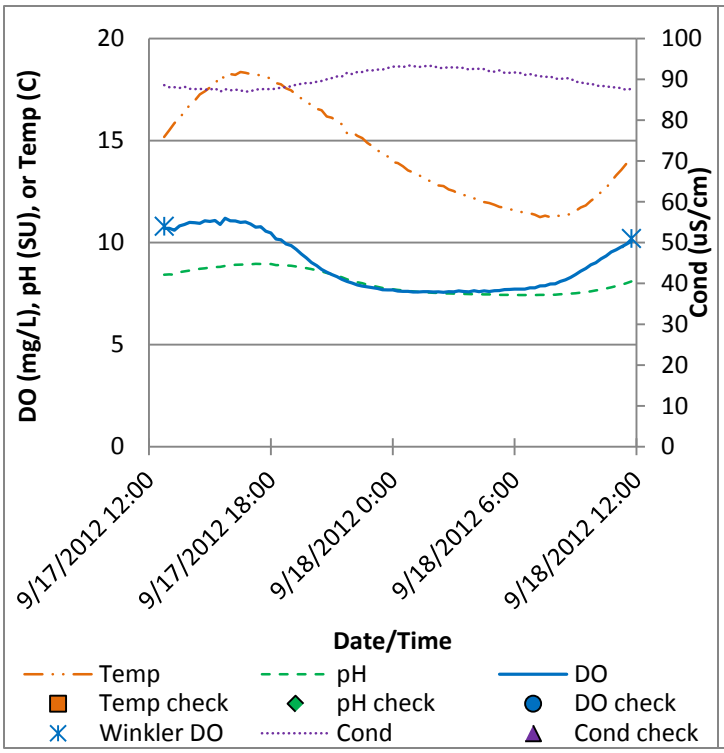
All dissolved oxygen data have been corrected using Winkler titration results.

34PAL124.3 (Palouse River at State Line)

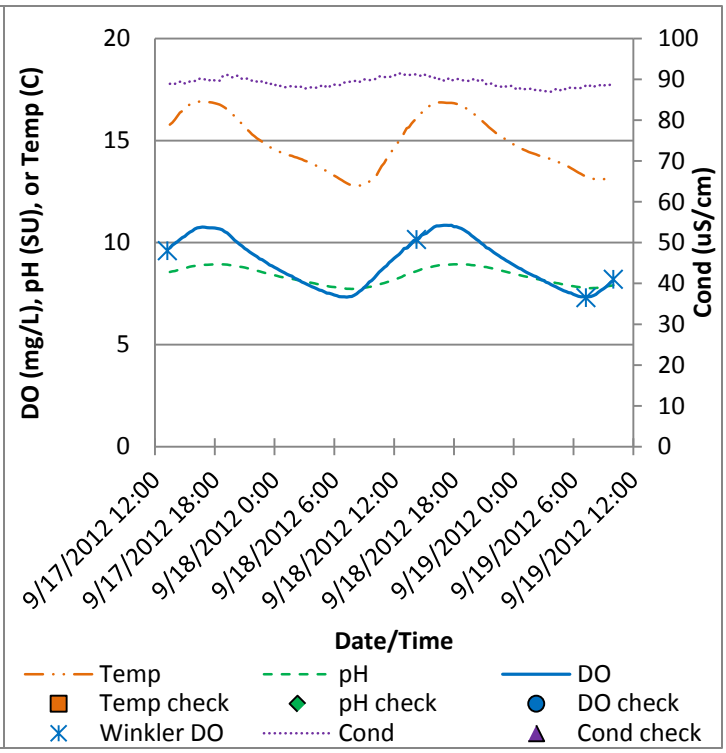




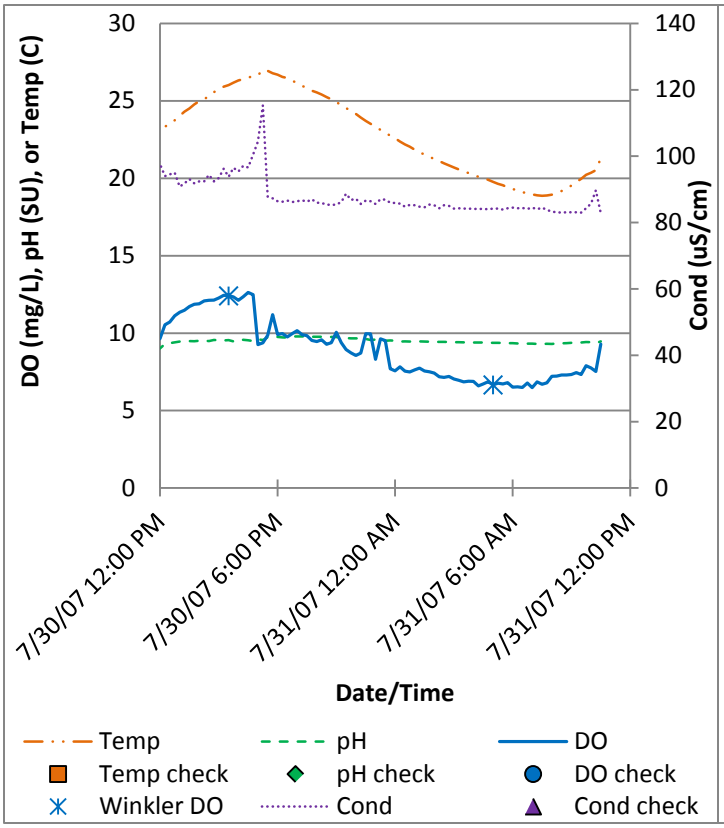
34PAL122.2 (Palouse River nr Loop Rd.)

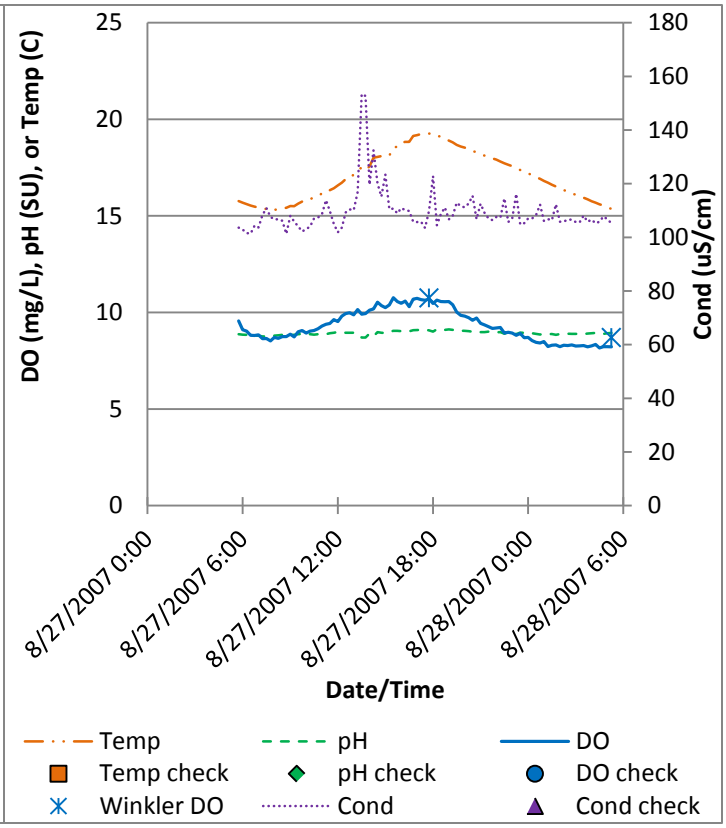


34PAL120.8 (Palouse River at S. River Rd.)

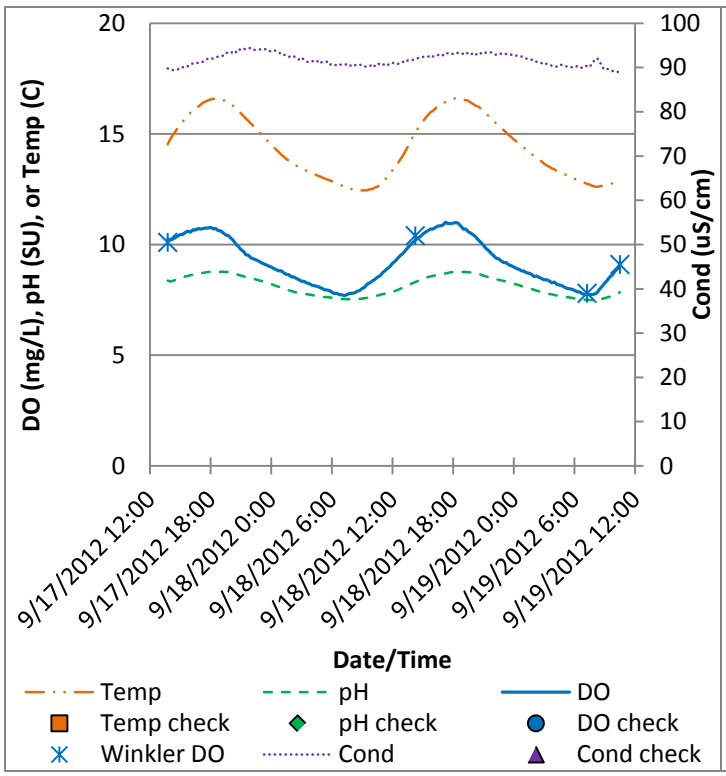


34PAL120.3 (Palouse River at Bridge St.)

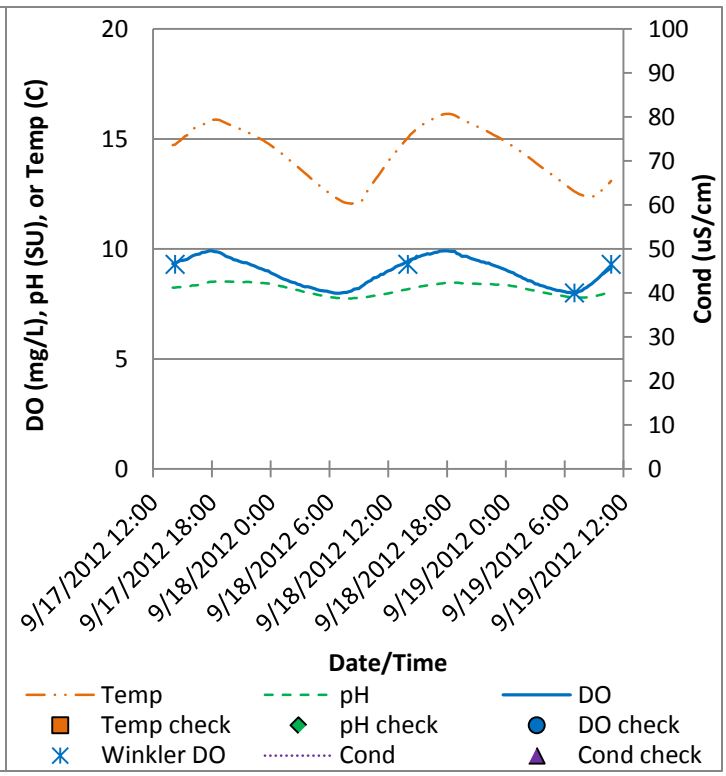




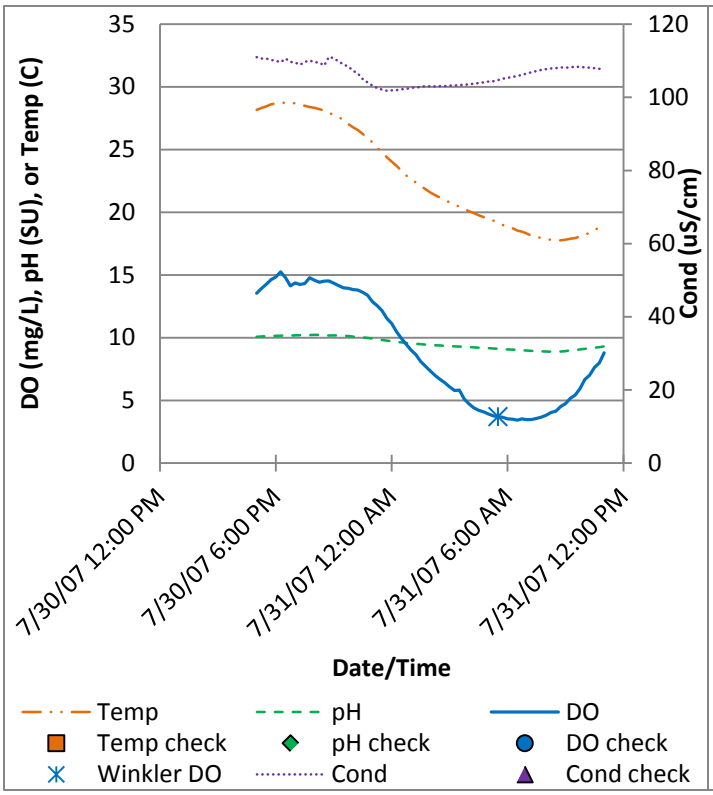
34PAL120.3 (Palouse River at Bridge St., cont'd)

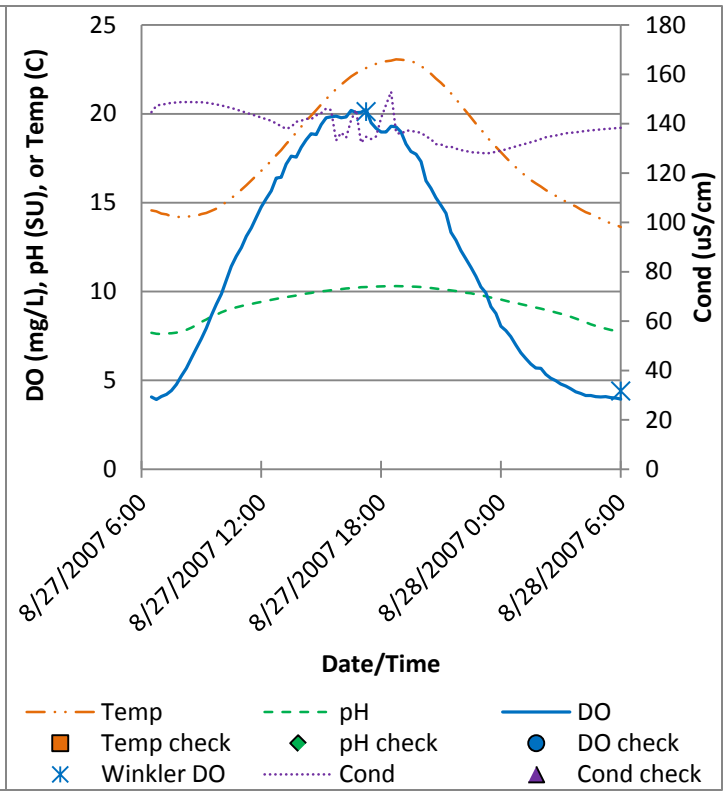


34PAL120.0 (Palouse River at Main St.)

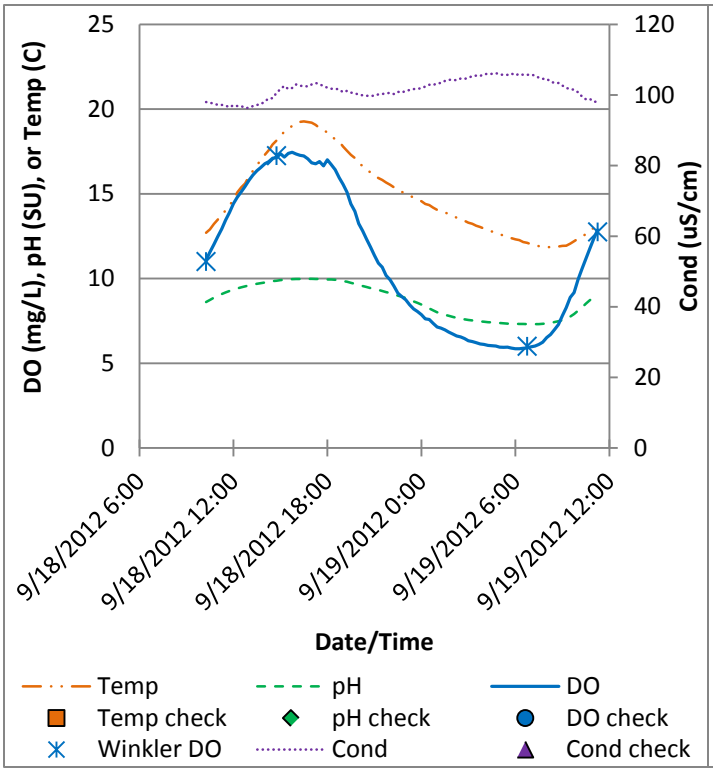


34PAL118.9 (Palouse River at Hwy 272)

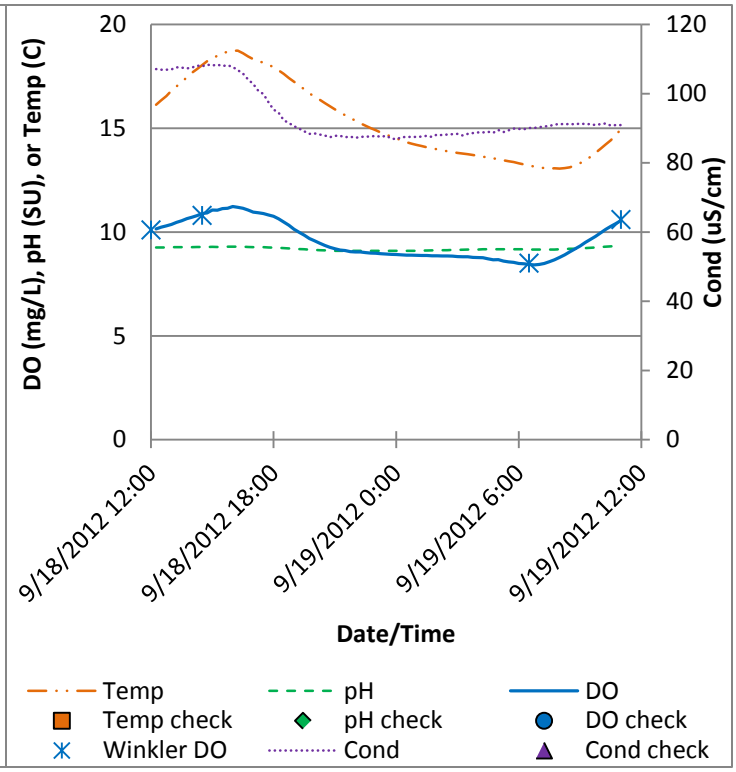




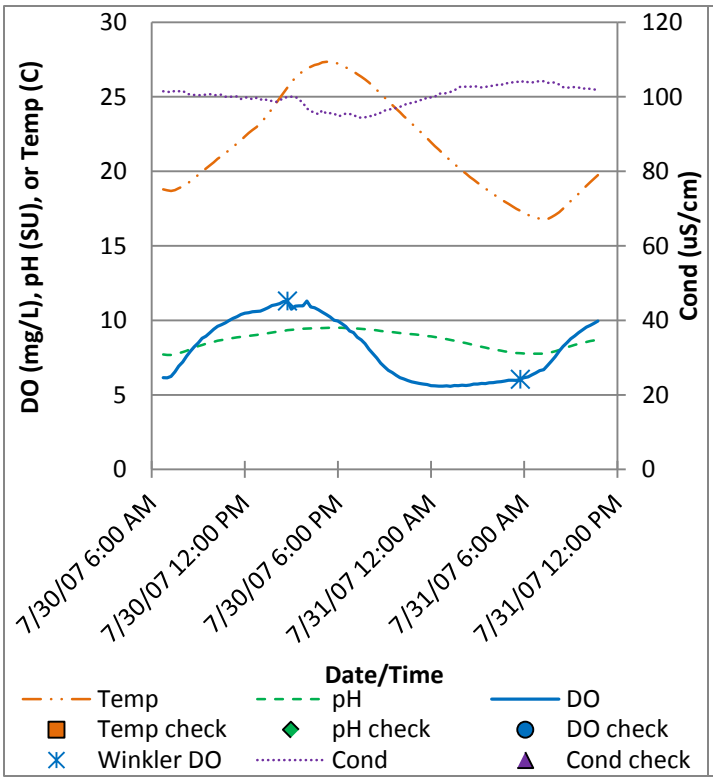
34PAL118.9 (Palouse River at Hwy 272, cont'd)

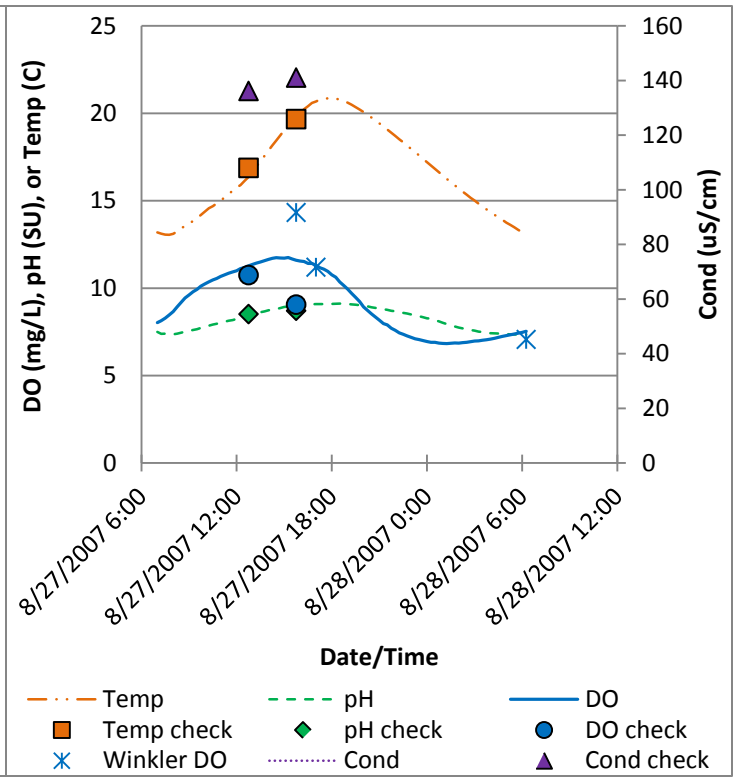


34PAL116.8 (Palouse River at Duffield Ck.)

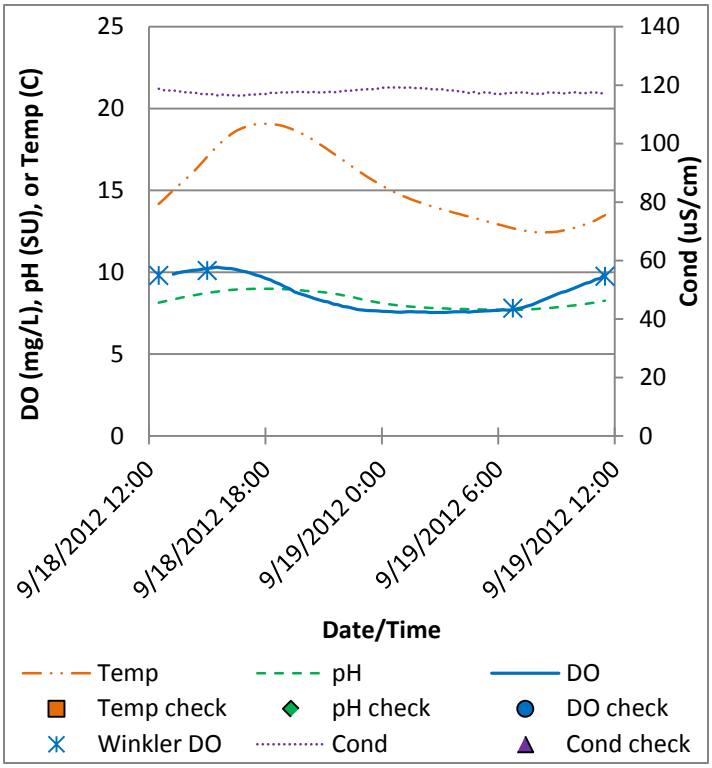


34PAL112.4 (Palouse River at Altergott Rd.)

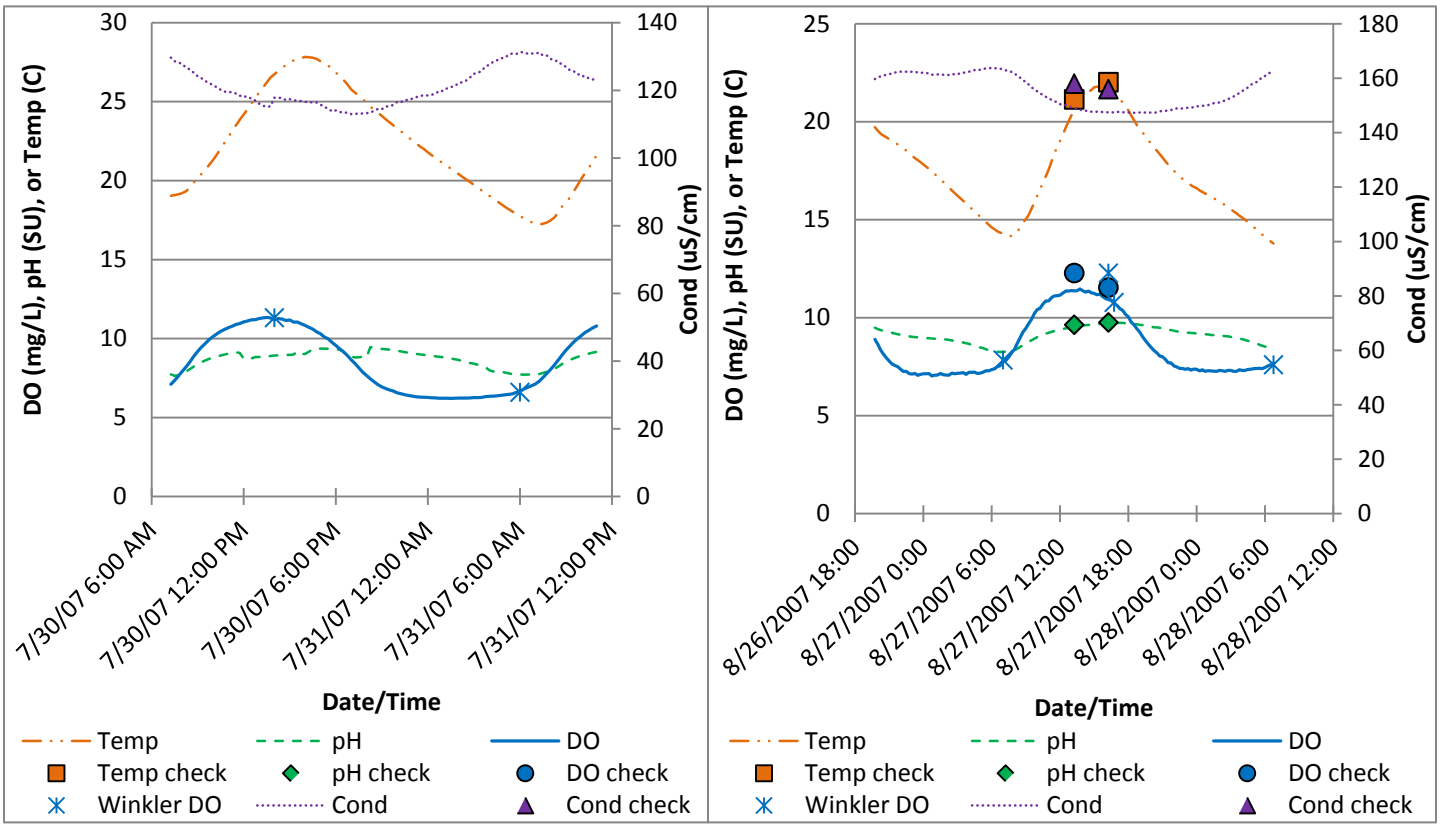




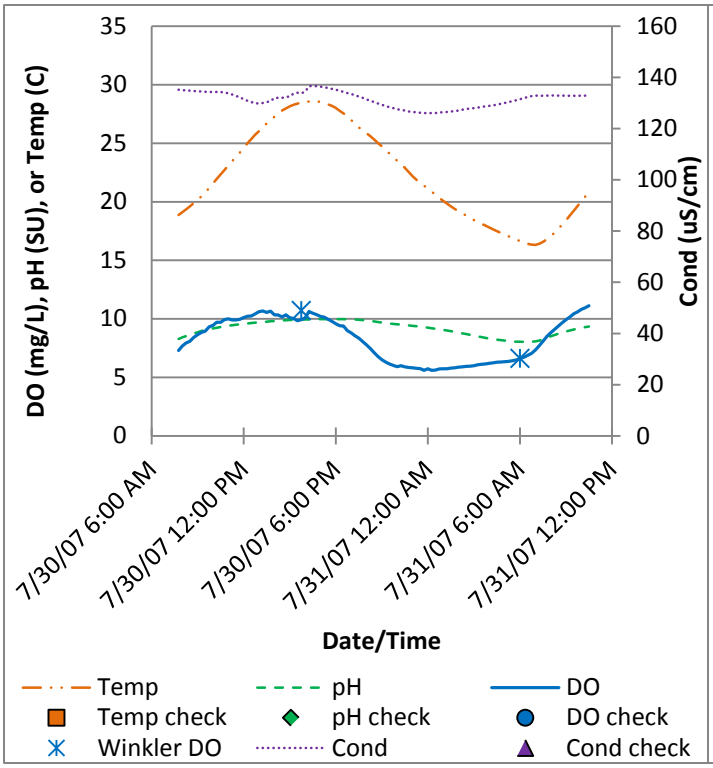
34PAL112.4 (Palouse River at Altergott Rd., cont'd)

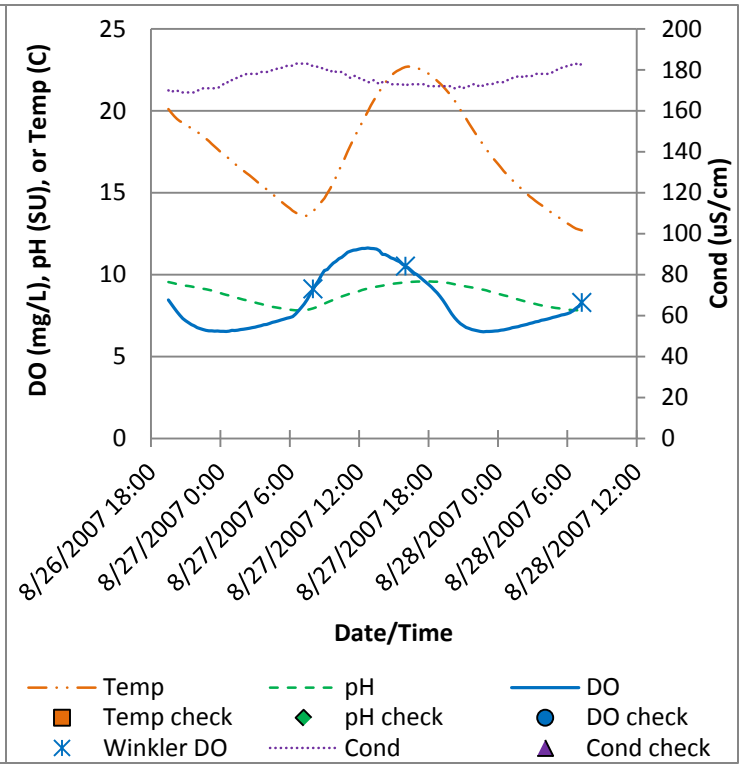


34PAL103.9 (Palouse River at Elberton)

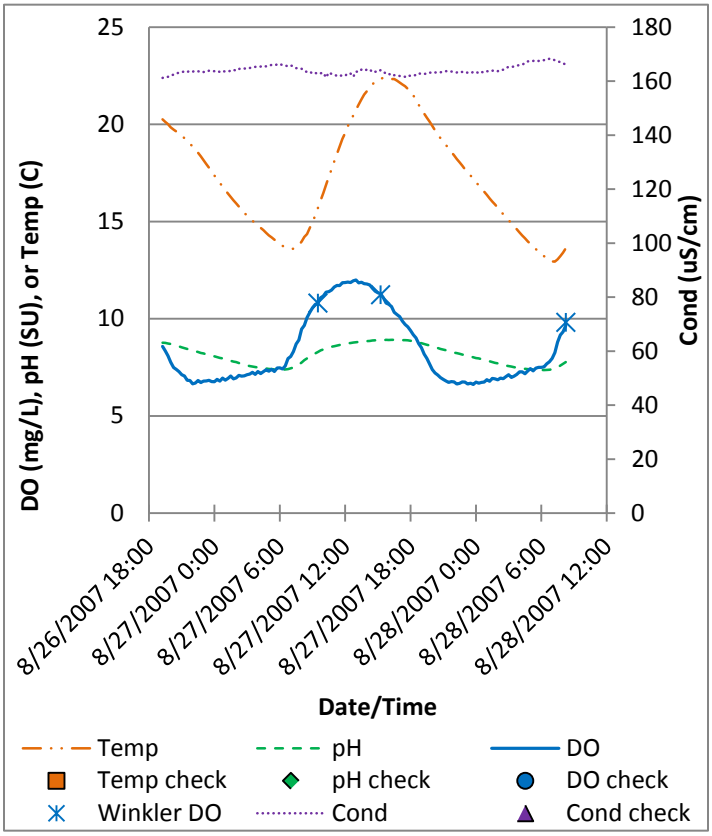


34PAL98.3 (Palouse River at Glenwood)

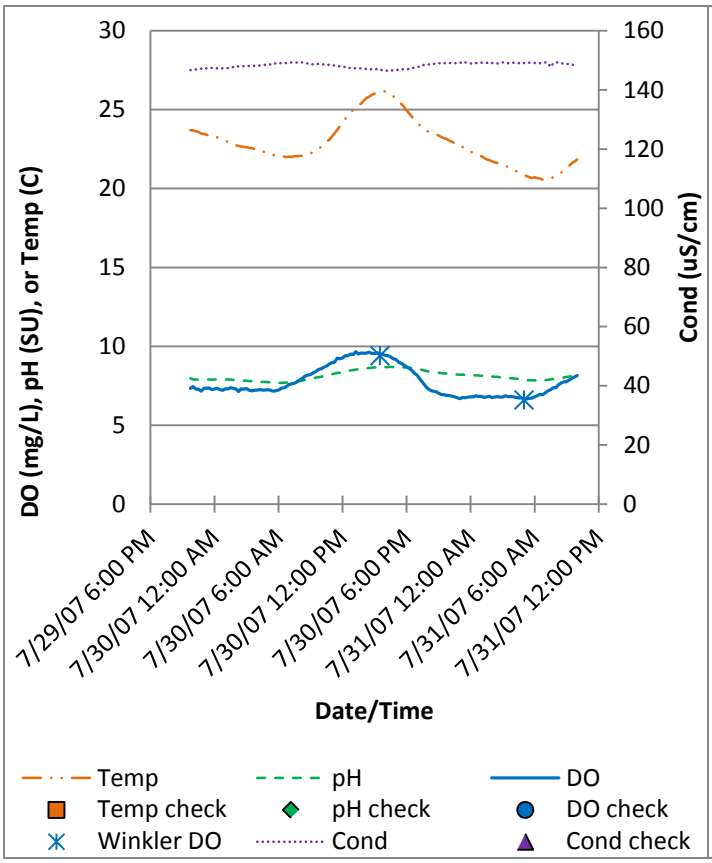


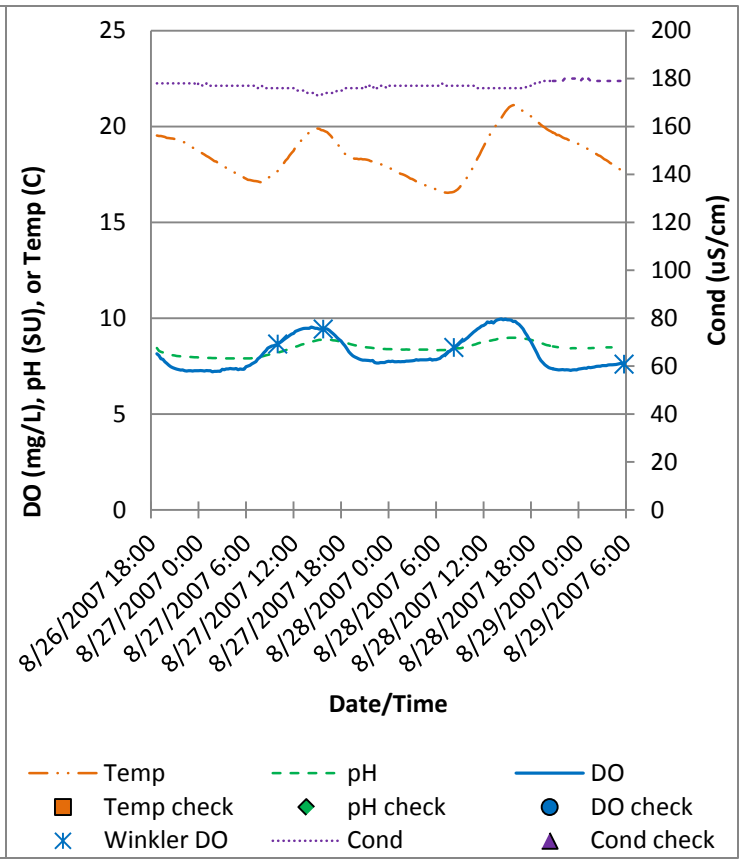


34PAL91.7 (Palouse River above Colfax)



34PAL91.5 (Palouse River above SF Palouse confluence)





Periphyton and Macrophyte Data

Table A-9. Abbreviations and units of measurement used in this section.

Abbreviation	Parameter	Unit of Measurement
Peri chl a	Areal periphyton biomass as chlorophyll a	mg/m^2
Peri AFDW	Areal periphyton biomass as ash-free dry weight	g/m^2
Macro chl a	Areal macrophyte biomass as chlorophyll a	mg/m^2
Macro AFDW	Areal macrophyte biomass as ash-free dry weight	g/m^2

Table A-10. Periphyton and macrophyte biomass results from the North Fork Palouse River DO-pH TMDL study.

Location ID	Date	Time	Peri chl a	Peri AFDW	Macro chl a	Macro AFDW
34PAL124.3	9/4/2007	8:55	26.8	8.78	4.75	7.33
34PAL120.3	9/4/2007	9:30	15.3	5.94	19.5	21.2
34PAL120.0	9/4/2007	9:50	50	9.03	4.34	1.39
34PAL112.4	9/4/2007	10:20	19.9	9.09	13.7	9.41
34PAL103.9	9/4/2007	10:50	19.3	9.54	308	74.7
34PAL91.7	9/4/2007	11:32	16.5	9.74	35.2	23.2
34PAL91.5	9/4/2007	12:50	41.9	10.8	212	48.6

Appendix B. Data Quality

The quality of continuous temperature data, Ecology temporary streamflow gage data, and flow measurements taken as part of temperature monitoring are evaluated in the Palouse River Temperature Total Maximum Daily Load report (Snouwaert and Stuart, 2013). The quality of biweekly flow measurements at 34PAL91.5 are evaluated in the Palouse River Fecal Coliform Total Maximum Daily Load report (Tarbutton et al., 2010).

This appendix describes the quality of data that were collected specifically for the North Fork dissolved oxygen and pH TMDL, including two synoptic surveys and a periphyton survey in 2007, and a supplemental continuous hydrolab survey in 2012.

All data used for the TMDL analysis were assessed for quality. Typically this was done by comparing some sort of quality metric such as a replicate precision statistic or an instrument calibration end check to a target Measurement Quality Objective (MQO). All data were found to be of appropriate quality for their use in the TMDL analysis, unless otherwise noted.

Sample Data Quality

Ecology took replicate field samples for laboratory parameter analyses. Field replicates are two samples collected from the same location and as close to the same time as possible. Ecology collects field replicates to check the precision of the entire process of sampling and analysis. The percentage of replicates taken per parameter can be seen in Tables B-1 and B-2. Both the frequency of field replicates and the precision of the replicated samples fell within the target levels set in the QAPP. This indicates a high level of precision suitable for TMDL analysis.

Laboratory duplicates consist of two subsamples taken from the same sample container and analyzed separately. These serve as a check the precision of the lab analysis. Ecology's Manchester Environmental Laboratory standard operating procedure (SOP) calls for duplicating a minimum of 5% of all samples (1/20 samples or 1/analytical batch). That goal was met or exceeded for all parameters except Total Phosphorus. Duplicate precision targets were met for all parameters (Tables B-1 and B-2).

Manchester Environmental Laboratory assesses bias for certain parameters through the use of matrix spikes. No bias targets were set for the N.F. Palouse DO-pH TMDL, however assessed bias were always less than ±10%, which is acceptable for meeting the goals of this project (Tables B-1 and B-2).

Field replicates and laboratory duplicates with result values of less than 5 times the detection limit were analyzed separately. These low-level sample results often have a higher relative variability than higher sample results. Low-level precision for ammonia-nitrogen, total suspended solids, and turbidity did not meet precision targets. However, these precision results are adequate to meet the study objectives.

Precision targets were not set for chlorophyll a and total non-volatile suspended solids. These sample parameters are of secondary importance, and the precision results are adequate to meet the study objectives.

Ecology submitted field blanks for analysis along with samples from the July 30th synoptic survey. In addition, Manchester Laboratory routinely ran lab blanks along with each analytical batch. All field and lab blanks resulted in non-detects, with one exception. One method blank sample run with a batch of chlorophyll *a* samples collected on September 4, 2007 had a value above the reporting limit. However, because all the sample values in the batch were more than 10 times the blank result, none of the data were qualified.

Table B-1. Lab precision and bias results for the North Fork Palouse DO-pH TMDL study.

Parameter	Number Samples	Number Duplicates	% duplicated	Target Precision	Average %RSD[1]		Target Bias[2]	Average Bias
					<5x DL	>=5x DL		
Alkalinity	42	3	7%	10% RSD	--	0.6%	N/A	
Ammonia-Nitrogen	42	4	10%	10% RSD	--	1.0%		-5%
Chloride	42	3	7%	5% RSD	--	0.9%		-1%
Chlorophyll	24	3	13%	[3]	--	7.1%		
Dissolved Organic Carbon	42	4	10%	10% RSD	4.9%	1.2%		+4%
Nitrite-Nitrate Nitrogen	42	2	5%	10% RSD	--	0.5%		-2%
Orthophosphate	42	2	5%	10% RSD	0.9%	0.0%		+4%
Total Non-volatile Suspended Solids	22	3	14%	[3]	0.0%	7.4%		
Total Organic Carbon	41	5	12%	10% RSD	--	2.0%		-3%
Total Phosphorus	42	1	2%	10% RSD	--	0.0%		+9%
Total Persulfate Nitrogen	42	4	10%	10% RSD	--	1.1%		+4%
Total Suspended Solids	22	3	14%	10% RSD	28.3%	0.0%		
Turbidity	22	2	9%	10% RSD	--	1.1%		

[1] Results at the detection limit were excluded from consideration.
[2] Targets for bias were not specified in the QAPP.
[3] Targets for precision were not specified for Chlorophyll or Total non-volatile suspended solids in the QAPP.

Table B-2. Total precision (field + lab) results for the North Fork Palouse DO-pH TMDL study.

Parameter	Number Samples	Number Replicates	% replicated	Target Precision	Average %RSD[1]	
					<5x DL	>=5x DL
Alkalinity	42	9	21%	10% RSD	--	0.5%
Ammonia-Nitrogen	42	9	21%	10% RSD	25.0%	7.5%
Chloride	42	9	21%	5% RSD	--	0.8%
Chlorophyll	24	7	29%	[2]	--	11.5%
Dissolved Organic Carbon	42	9	21%	10% RSD	5.0%	1.2%
Nitrite-Nitrate Nitrogen	42	9	21%	10% RSD	0.0%	3.9%
Orthophosphate	42	9	21%	10% RSD	0.5%	4.5%
Total Non-volatile Suspended Solids	22	7	32%	[2]	--	17.7%
Total Organic Carbon	41	8	20%	10% RSD	1.0%	2.4%
Total Phosphorus	42	8	19%	10% RSD	--	2.7%
Total Persulfate Nitrogen	42	9	21%	10% RSD	--	7.2%
Total Suspended Solids	22	7	32%	10% RSD	21.7%	6.7%
Turbidity	22	7	32%	10% RSD	14.5%	6.1%

[1] Results at the detection limit were excluded from consideration.
[2] Targets for precision were not specified Chlorophyll or Total non-volatile suspended solids in the QAPP.

Hydrolab Data Quality

Ecology calibrated all field monitoring equipment according to manufacturer's specifications using certified standards. Hydrolab® meters were calibrated prior to each monitoring event, and calibrations were checked after each event to assess calibration drift.

Conductivity and pH accuracy were assessed through calibration post-checks. Table B-3 shows the targets to accept, qualify, or reject data. Qualified data was used with caution for TMDL analysis, accounting for the range of possible error indicated by post-check results. Rejected data was not used.

Table B-3. Post-check targets for calibration drift for conductivity and pH.

Parameter	Difference between post-check value and true buffer value to:		
	Accept	Qualify	Reject
Conductivity	≤ 5%	> 5% and ≤ 10%	> 10%
pH	≤ 0.15	> 0.15 and ≤ 0.5	> 0.5

All conductivity and pH post-checks were within target values with the following exceptions:

- During the July 2007 survey, conductivity data were qualified at 34PAL91.5 (Palouse R. above SF Palouse R. confluence), 34PAL112.4 (Palouse R. at Altergott Rd.), and 34SIL00.0 (Silver Ck. at mouth).
- During the July 2007 survey, pH data were qualified at 34PAL120.3 (Palouse R. at Bridge St.) and 34PAL103.9 (Palouse R. at Elberton).
- During the August 2007 survey, conductivity data were qualified at 34PAL98.3 (Palouse R. at Glenwood), 34PAL91.5 (Palouse R. above SF Palouse R. confluence), and 34PAL118.9 (Palouse R. at Hwy 272), as well as point measurements taken by one of the sampling teams. Conductivity data were rejected at 34PAL112.4 (Palouse R. at Altergott Rd.)
- During the August 2007 survey, pH data were qualified at 34PAL112.4 (Palouse R. at Altergott Rd.), 34PAL103.9 (Palouse River at Elberton), 34SIL00.0 (Silver Ck. at mouth), and 34PAL124.3 (Palouse River at state line).
- During the September 2012 survey, conductivity data were rejected at 34PAL120.0 (Palouse R at Main St.).

DO accuracy was assessed through comparison with Winkler titration results. At least three Winkler samples were taken with each Hydrolab used for deployment or spot measurements. All DO data were corrected based on Winkler results. The reason for this is that the technique for DO calibration, which is based on water saturated air, results in a certain degree of bias or mis-calibration. Correction of this data using Winkler creates a uniform standard, and eliminates most or all of this error. Corrected DO data are of a higher quality than if the data were used "raw." All DO data are of acceptable quality and do not need qualification.

Flow Measurement Data Quality

During the synoptic nutrient surveys, replicate flow measurements were taken to assess variability of the velocity meters. 17% of flow measurements were replicated, and replicate measurement pairs had a precision of 10.0% RSD, which is adequate to meet the goals of this project.

Periphyton and Macrophyte Data Quality

Periphyton and macrophytes grow unevenly on the river bottom. This uneven distribution likely contributes the largest source of uncertainty in measurements of periphyton and macrophyte biomass. This uncertainty was minimized by following EAP's field protocol for periphyton and macrophyte sampling (Mathieu et al., 2013).

Other Ecology Data Quality

Ambient Monitoring Data
This study utilized ambient monitoring data collected by Ecology's Freshwater Monitoring Unit (FMU). This data is collected under a Quality Assurance Monitoring Plan (Hallock and Ehinger, 2003) and is of a high quality suitable for meeting the goals of this project.

1987 Receiving Water Study
This study also used data collected by Ecology during a 1987 study of Palouse WWTP and the N.F. Palouse River (Kendra, 1988). Replicate sample results collected indicate that data quality is adequate for meeting the goals of this project.

Non-Ecology Data Quality

This study utilized several data sources from outside Ecology:

- U.S. Geological Survey (USGS) streamflow data from the gaging station at Potlatch, ID.
- USGS's 1994 study of nutrients, algae, and water quality in the Palouse watershed (Greene et al., 1997).
- Effluent flow and water quality from Palouse WWTP reported by the city of Palouse in their Discharge Monitoring Reports (DMRs) to Ecology.
- National Weather Service (NWS) meteorology data collected at Pullman-Moscow Regional Airport.

These organizations all collect data using standard protocols to insure data quality. All external data are adequate for meeting the goals of this project.

Appendix C. QUAL2Kw Model Inputs and Calibration

QUAL2Kw Modeling Framework

The QUAL2Kw 6.0 modeling framework (Pelletier and Chapra, 2008) was used to develop the loading capacity for nutrients and to make predictions about water quality under various scenarios. The QUAL2Kw model framework and complete documentation are available at http://www.ecy.wa.gov/programs/eap/models.html.

The QUAL2Kw 6.0 modeling framework has the following characteristics:

- One dimensional. The channel is well-mixed vertically and laterally. Also includes up to two optional transient storage zones connected to each main channel reach (surface and hyporheic transient storage zones).
- Non-steady, non-uniform flow using kinematic wave flow routing. Continuous simulation with time-varying boundary conditions for periods of up to one year.
- Dynamic heat budget. The heat budget and temperature are simulated as a function of meteorology on a continuously varying or repeating diel time scale.
- Dynamic water-quality kinetics. All water quality state variables are simulated on a continuously varying or repeating diel time scale for biogeochemical processes.
- Heat and mass inputs. Point and non-point loads and abstractions are simulated.
- Phytoplankton and bottom algae in the water column, as well as sediment diagenesis, and heterotrophic metabolism in the hyporheic zone are simulated. Phytoplankton transport can be turned off to use the phytoplankton model to simulate macrophytes instead.
- Variable stoichiometry. Luxury uptake of nutrients by the bottom algae (periphyton) is simulated with variable stoichiometry of N and P.

Figure C-1 shows a schematic of the model kinetics and mass transfer processes in QUAL2Kw. Table C-1 lists these processes as well as the state variables.

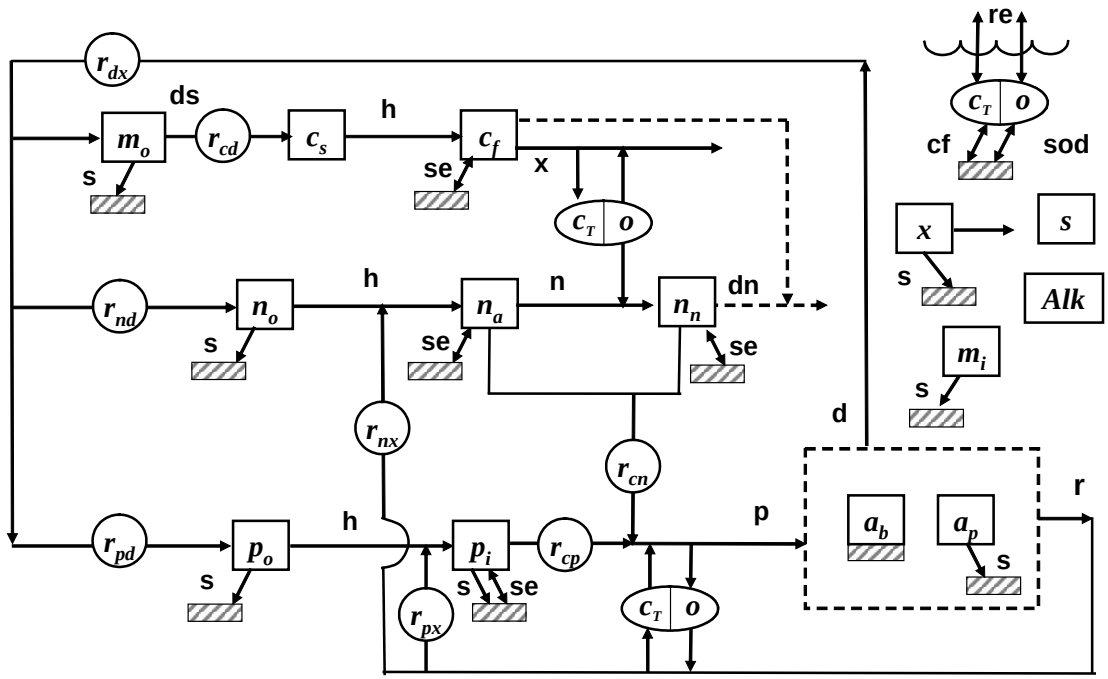


Figure C-1. Model kinetics and mass transfer processes in QUAL2Kw.

Table C-1. Processes and state variables in QUAL2Kw.

State Variables			
Variable	Symbol	Units	Measured as
Conductivity	s	µmhos	COND
Inorganic suspended solids	m_i	mgD/L	TNVSS
Dissolved oxygen	o	mgO_2/L	DO
Slow-reacting CBOD	c_s	mg O_2/L	r_{oc} * DOC
Fast-reacting CBOD	c_f	mg O_2/L	r_{oc} * DOC
Organic nitrogen	n_o	µgN/L	TN – NO_3N NO_2N– NH_4N
Ammonia nitrogen	n_a	µgN/L	NH_4N
Nitrate nitrogen	n_n	µgN/L	NO_3N+NO_2N
Organic phosphorus	p_o	µgP/L	TP - Orthophosphate
Inorganic phosphorus	p_i	µgP/L	Orthophosphate
Phytoplankton	a_p	µgA/L	Chlorophyll *a*
Detritus	m_o	mgD/L	r_{dc} (TOC – DOC)
Alkalinity	*Alk*	$mgCaCO_3/L$	ALK
Total inorganic carbon	c_T	mole/L	Calculation from pH and alkalinity
Bottom algae biomass	a_b	gD/m^2	Periphyton biomass dry weight
Bottom algae nitrogen	IN_b	mgN/m^2	Periphyton biomass N
Bottom algae phosphorus	IP_b	mgP/m^2	Periphyton biomass P

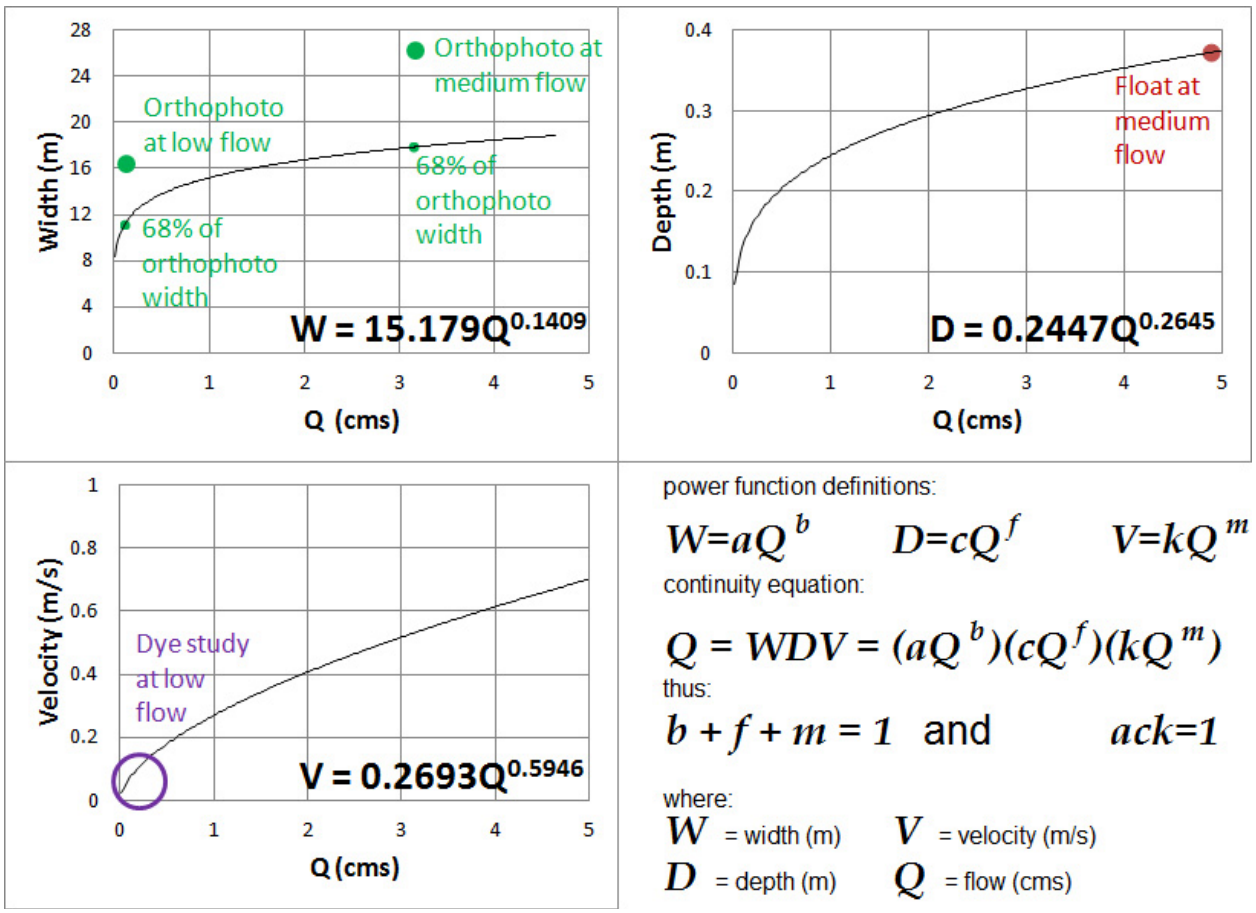
Kinetic Processes		Mass Transfer Processes	
Process	Symbol	Process	Symbol
dissolution	ds	reaeration	re
hydrolysis	h	settling	s
oxidation	x	sediment oxygen demand	SOD
nitrification	n	sediment exchange	se
denitrification	dn	sediment inorganic carbon flux	cf
photosynthesis	p		
death	d		
respiration/excretion	r		

Note: in Figure C-1 and Table C-1, r_{xx} refers to a stoichiometric ratio. The letters used in the subscripts are: c = carbon; d = dry weight; n = nitrogen; p = phosphorus. The same letters (in caps) are used in the Units column in Table C-1.

Segmentation and Channel Geometry

The QUAL2Kw model of the North Fork Palouse River simulates the portion of the river between the state line (34PAL124.3) and Glenwood (34PAL98.3). This length of river was divided into 220 model segments, each 200 meters in length.

Channel geometry for each model segment was calculated as power functions relating width, depth, and velocity to flow. Figure C-2 shows how observed data were used to calculate the power functions, using model segment 193 as an example. Table C-2 shows the power functions for each model segment.



Note: The functional width of a stream channel for calculating geometry is often less than the full wetted width due to the fact that most of the flow is concentrated in the center portion of the channel (thalweg). A functional width of 68% of the orthophoto wetted width was applied universally to develop the width rating curves for all model segments. 68% is the functional width ratio that best predicts dye travel. (See Rhodamine dye / Time of Travel calibration plots below under "Model Goodness-of-fit").

Figure C-2. Schematic showing derivation procedure for power functions describing channel geometry, using segment 193 as an example.

Table C-2. Power functions used to define channel geometry in QUAL2Kw model of the North Fork Palouse River.

Model Segment	Location	Width		Depth		Velocity		Model Segment	Location	Width		Depth		Velocity	
		Coefficient	Exponent	Coefficient	Exponent	Coefficient	Exponent			Coefficient	Exponent	Coefficient	Exponent	Coefficient	Exponent
1	State Line	13.708	0.034	0.938	0.071	0.078	0.896	111		11.880	0.084	0.191	0.124	0.442	0.792
2		9.611	0.010	0.938	0.071	0.111	0.919	112		14.093	0.229	0.247	0.258	0.287	0.513
3		9.116	0.023	0.662	0.101	0.166	0.875	113		11.799	0.111	0.217	0.191	0.391	0.698
4		8.791	0.047	0.398	0.171	0.286	0.782	114		12.310	0.103	0.238	0.239	0.341	0.658
5		9.656	0.079	0.347	0.197	0.299	0.723	115		12.403	0.129	0.211	0.176	0.383	0.696
6		9.362	0.096	0.662	0.101	0.161	0.802	116		11.984	0.118	0.380	0.177	0.220	0.705
7		11.170	0.159	0.576	0.117	0.155	0.724	117		11.656	0.218	0.244	0.252	0.352	0.530
8		9.141	0.020	0.451	0.150	0.243	0.829	118		13.300	0.037	0.263	0.255	0.286	0.708
9		8.300	0.010	0.248	0.240	0.486	0.750	119		12.789	0.010	0.357	0.188	0.219	0.802
10		10.908	0.026	0.469	0.145	0.196	0.830	120		9.688	0.064	0.293	0.229	0.352	0.706
11		10.855	0.038	0.545	0.124	0.169	0.838	121		8.366	0.012	0.515	0.130	0.232	0.858
12	Nr. Loop Rd.	8.710	0.010	0.517	0.131	0.222	0.859	122		9.565	0.083	0.285	0.236	0.367	0.681
13		10.085	0.010	0.564	0.120	0.176	0.870	123		12.205	0.063	0.224	0.206	0.366	0.730
14		9.483	0.010	0.397	0.172	0.266	0.818	124		15.015	0.032	0.502	0.133	0.133	0.835
15		10.176	0.012	0.473	0.143	0.208	0.844	125		15.903	0.110	0.451	0.149	0.140	0.741
16		10.495	0.041	0.450	0.151	0.212	0.808	126		14.283	0.096	0.604	0.111	0.116	0.794
17		11.852	0.022	0.549	0.123	0.154	0.855	127		12.583	0.125	0.349	0.192	0.228	0.683
18		8.803	0.015	0.384	0.178	0.296	0.808	128		10.902	0.083	0.191	0.124	0.481	0.793
19		12.727	0.035	0.596	0.113	0.132	0.852	129		12.338	0.045	0.195	0.136	0.415	0.819
20		10.071	0.096	0.724	0.093	0.137	0.811	130		13.743	0.124	0.333	0.202	0.219	0.674
21		11.276	0.075	0.467	0.145	0.190	0.780	131		11.642	0.121	0.252	0.266	0.340	0.613
22	River Rd.	8.938	0.010	0.770	0.087	0.145	0.903	132		10.745	0.039	0.274	0.245	0.340	0.716
23		11.796	0.029	0.447	0.152	0.189	0.819	133		11.725	0.128	0.217	0.191	0.393	0.681
24		9.019	0.010	0.585	0.115	0.189	0.875	134		12.405	0.080	0.223	0.205	0.361	0.715
25	Bridge St.	10.601	0.076	0.577	0.117	0.163	0.807	135		13.315	0.133	0.343	0.196	0.219	0.671
26		8.771	0.073	0.653	0.103	0.175	0.824	136		12.782	0.068	0.481	0.139	0.162	0.793
27		10.631	0.033	0.716	0.094	0.131	0.873	137		14.373	0.047	0.320	0.210	0.218	0.743
28	Main St; Pal WWTP	8.361	0.076	0.583	0.116	0.205	0.808	138		10.170	0.089	0.229	0.219	0.429	0.692
29		9.912	0.010	0.558	0.121	0.181	0.869	139		12.405	0.025	0.251	0.266	0.321	0.709
30		11.534	0.134	0.690	0.098	0.126	0.768	140		14.858	0.152	0.367	0.183	0.183	0.666
31		10.023	0.110	0.365	0.188	0.273	0.702	141		11.218	0.249	0.333	0.201	0.268	0.550
32		9.749	0.048	0.332	0.207	0.309	0.745	142		8.810	0.090	0.241	0.245	0.471	0.665
33		11.240	0.060	0.436	0.157	0.204	0.783	143		9.305	0.089	0.249	0.263	0.431	0.648
34		11.838	0.028	0.573	0.118	0.148	0.853	144		13.647	0.016	0.412	0.163	0.178	0.822
35		15.438	0.032	0.677	0.100	0.096	0.868	145		17.009	0.032	0.591	0.113	0.099	0.855
36	Hwy 272	13.211	0.080	0.985	0.068	0.077	0.852	146		13.001	0.253	0.221	0.200	0.348	0.547
37		9.143	0.050	0.581	0.117	0.188	0.834	147		14.079	0.041	0.195	0.136	0.364	0.823
38		10.478	0.158	0.380	0.180	0.251	0.662	148		8.528	0.081	0.213	0.180	0.552	0.738
39		10.925	0.133	0.398	0.172	0.230	0.695	149		10.836	0.197	0.279	0.240	0.331	0.563
40		13.471	0.025	0.603	0.112	0.123	0.863	150		13.886	0.043	0.260	0.257	0.277	0.699
41		14.191	0.010	0.434	0.157	0.162	0.833	151		11.780	0.017	0.245	0.253	0.347	0.730
42		12.613	0.062	0.465	0.146	0.171	0.792	152		9.036	0.045	0.229	0.219	0.483	0.736
43		8.465	0.015	0.372	0.184	0.318	0.801	153		13.303	0.039	0.650	0.103	0.116	0.859
44		12.252	0.101	0.642	0.105	0.127	0.794	154		12.887	0.041	0.326	0.205	0.238	0.753
45		15.658	0.054	1.013	0.066	0.063	0.880	155		9.466	0.010	0.220	0.197	0.481	0.793
46		8.532	0.094	0.791	0.085	0.148	0.821	156		11.759	0.015	0.268	0.249	0.317	0.736
47		10.601	0.010	0.452	0.150	0.208	0.840	157		11.088	0.021	0.319	0.210	0.282	0.769
48		20.084	0.037	0.718	0.094	0.069	0.869	158		10.201	0.085	0.242	0.247	0.406	0.668
49		8.197	0.119	0.735	0.091	0.166	0.790	159	Elberton	11.262	0.049	0.248	0.261	0.358	0.690
50		13.186	0.010	0.275	0.249	0.276	0.741	160	Silver Ck.	10.834	0.107	0.541	0.124	0.171	0.769
51		8.860	0.082	0.502	0.135	0.225	0.783	161		9.593	0.100	0.940	0.071	0.111	0.828
52		10.337	0.010	0.489	0.138	0.198	0.852	162		13.116	0.065	0.457	0.147	0.167	0.787
53	Duffield Ck.	9.829	0.047	0.420	0.162	0.242	0.791	163		12.682	0.040	0.368	0.182	0.214	0.778

(continued)

Seg	Location	Width		Depth		Velocity		Seg	Location	Width		Depth		Velocity	
		Coeff	Exp	Coeff	Exp	Coeff	Exp			Coeff	Exp	Coeff	Exp	Coeff	Exp
54		9.357	0.099	0.635	0.106	0.168	0.795	164		11.159	0.100	0.222	0.213	0.403	0.688
55		14.668	0.064	0.858	0.078	0.079	0.858	165		8.095	0.151	0.290	0.231	0.427	0.617
56		8.831	0.103	0.718	0.094	0.158	0.804	166		9.408	0.156	0.233	0.238	0.457	0.606
57		9.711	0.094	0.381	0.178	0.270	0.727	167		13.792	0.048	0.660	0.102	0.110	0.850
58		9.130	0.023	0.555	0.122	0.197	0.855	168		14.453	0.022	0.615	0.109	0.112	0.869
59		10.645	0.095	0.614	0.110	0.153	0.796	169		14.978	0.071	0.410	0.164	0.163	0.765
60		7.682	0.177	0.393	0.173	0.331	0.651	170		11.133	0.123	0.456	0.147	0.197	0.730
61		7.812	0.066	0.440	0.154	0.291	0.780	171		11.862	0.087	0.431	0.156	0.196	0.757
62		11.130	0.051	0.604	0.111	0.149	0.838	172		9.942	0.088	0.366	0.183	0.275	0.728
63		11.671	0.037	0.665	0.101	0.129	0.861	173		13.297	0.094	0.363	0.185	0.207	0.721
64		9.686	0.093	0.489	0.138	0.211	0.768	174		8.047	0.112	0.311	0.215	0.399	0.673
65		8.649	0.112	0.363	0.187	0.319	0.701	175		9.317	0.128	0.223	0.215	0.481	0.657
66		12.240	0.059	0.581	0.116	0.141	0.825	176		13.194	0.120	0.216	0.197	0.351	0.683
67		15.730	0.027	0.601	0.112	0.106	0.862	177		12.576	0.090	0.230	0.231	0.346	0.680
68		10.681	0.073	0.695	0.097	0.135	0.830	178		21.060	0.068	0.522	0.129	0.091	0.804
69		8.712	0.169	0.546	0.123	0.210	0.708	179		18.787	0.085	0.170	0.069	0.312	0.846
70		12.186	0.064	0.615	0.109	0.133	0.827	180		12.807	0.140	0.174	0.079	0.450	0.781
71		10.728	0.049	0.674	0.099	0.138	0.851	181		9.667	0.078	0.242	0.258	0.428	0.664
72		12.448	0.052	0.515	0.131	0.156	0.817	182		13.484	0.076	0.305	0.220	0.243	0.705
73		7.196	0.076	0.583	0.115	0.239	0.809	183		13.633	0.172	0.240	0.254	0.306	0.574
74		8.266	0.099	0.395	0.172	0.307	0.729	184		10.320	0.108	0.232	0.236	0.417	0.655
75		8.170	0.049	0.298	0.228	0.410	0.723	185		21.416	0.010	0.534	0.126	0.088	0.864
76		9.440	0.124	0.589	0.114	0.180	0.762	186		12.202	0.055	0.389	0.172	0.211	0.773
77		13.484	0.055	0.251	0.259	0.295	0.686	187		13.590	0.025	0.498	0.135	0.148	0.840
78		13.454	0.096	0.631	0.106	0.118	0.797	188	Brush Ck.	23.173	0.010	0.836	0.080	0.052	0.910
79		16.027	0.030	0.543	0.124	0.115	0.846	189		10.980	0.066	0.528	0.126	0.172	0.807
80	Cedar Ck.	12.492	0.010	1.411	0.047	0.057	0.943	190		12.186	0.188	0.625	0.107	0.131	0.706
81		7.892	0.125	0.515	0.131	0.246	0.745	191		11.836	0.140	0.191	0.131	0.442	0.729
82		12.321	0.192	0.602	0.112	0.135	0.696	192		12.706	0.092	0.203	0.163	0.388	0.745
83		9.135	0.211	0.604	0.111	0.181	0.678	193		15.179	0.141	0.245	0.265	0.269	0.595
84		13.228	0.385	0.754	0.089	0.100	0.526	194		21.971	0.030	0.228	0.226	0.200	0.744
85		12.647	0.214	0.384	0.176	0.206	0.611	195		14.154	0.078	0.292	0.228	0.242	0.694
86		8.561	0.178	0.277	0.243	0.421	0.578	196		11.755	0.097	0.245	0.266	0.347	0.637
87		12.201	0.066	0.384	0.176	0.214	0.758	197		15.326	0.098	0.235	0.242	0.278	0.660
88		11.109	0.154	0.593	0.113	0.152	0.733	198		18.262	0.029	0.574	0.116	0.095	0.855
89		11.627	0.072	0.460	0.146	0.187	0.782	199		21.701	0.015	0.617	0.108	0.075	0.877
90	Altergott Rd.	10.372	0.080	0.316	0.213	0.305	0.707	200		12.764	0.074	0.204	0.166	0.384	0.761
91		9.374	0.010	0.341	0.197	0.313	0.793	201		16.035	0.081	0.151	0.004	0.413	0.915
92		10.011	0.081	0.425	0.158	0.235	0.761	202		13.211	0.109	0.239	0.251	0.317	0.641
93		13.313	0.010	0.688	0.097	0.109	0.893	203		18.360	0.010	0.472	0.141	0.116	0.849
94		10.845	0.033	0.420	0.160	0.220	0.806	204		17.748	0.024	0.236	0.244	0.239	0.731
95		8.641	0.077	0.719	0.093	0.161	0.830	205		14.303	0.046	0.304	0.218	0.230	0.736
96		8.184	0.088	0.217	0.191	0.563	0.721	206		10.804	0.024	0.209	0.179	0.443	0.797
97		10.108	0.144	0.482	0.139	0.205	0.716	207		11.117	0.051	0.217	0.198	0.415	0.751
98		16.157	0.068	0.388	0.174	0.160	0.758	208		14.131	0.129	0.309	0.215	0.229	0.656
99		10.382	0.077	0.415	0.162	0.232	0.761	209		15.149	0.055	0.304	0.218	0.217	0.727
100		9.211	0.151	0.352	0.191	0.309	0.658	210		16.230	0.052	0.235	0.243	0.262	0.705
101		12.123	0.063	0.699	0.096	0.118	0.841	211		23.043	0.010	0.394	0.169	0.110	0.821
102		16.642	0.014	0.811	0.082	0.074	0.903	212		17.815	0.207	0.444	0.150	0.126	0.643
103		8.808	0.112	0.323	0.209	0.352	0.680	213		17.028	0.230	0.242	0.259	0.243	0.511
104		14.166	0.069	0.352	0.191	0.201	0.740	214		14.301	0.132	0.189	0.124	0.370	0.744
105		17.736	0.057	0.782	0.085	0.072	0.858	215		14.068	0.055	0.300	0.221	0.237	0.724
106		15.954	0.093	0.229	0.220	0.273	0.688	216		13.407	0.133	0.407	0.163	0.183	0.704
107		11.371	0.138	0.193	0.131	0.455	0.731	217		10.435	0.112	0.211	0.184	0.454	0.704
108		10.633	0.154	0.250	0.265	0.376	0.581	218		12.045	0.058	0.507	0.131	0.164	0.811
109		10.700	0.111	0.296	0.227	0.316	0.662	219	Clear Ck.	8.489	0.018	0.263	0.250	0.448	0.731
110		12.609	0.147	0.448	0.150	0.177	0.703	220	Glenwood	6.391	0.229	0.400	0.166	0.391	0.605

Note: only the velocity and depth power functions were used for input to the QUAL2Kw model. The model software calculates the width function based on the continuity equation shown in Figure C-2. All three power functions are presented here for reference.

Boundary Condition Inputs

The boundary conditions in a water quality model are a description of streamflow and water quality at locations where water enters the model domain. For the continuous version of QUAL2Kw, time-series are needed for each constituent input (Table C-3) at each model boundary. For the North Fork Palouse River model, boundary inputs occur at the following locations:

- Headwater boundary at the WA/ID state line
- Palouse Wastewater Treatment Plant effluent
- Tributaries (Duffield Ck., Cedar Ck., Silver Ck., Brush Ck., and Clear Ck.)

Only one of the tributaries, Silver Creek, was sampled. Therefore the same water quality inputs were used for all the tributaries based on data from Silver Creek. However, streamflow was assumed to be different for the different tributaries.

In many water quality models, groundwater represents an additional source of water to the model domain. However, analysis of the water balance using the QUAL2Kw model for the North Fork Palouse River indicates that there are no significant groundwater gains at low flow. Therefore no groundwater inputs are included in the model.

The continuous model that was used for model calibration was constructed so that different parts of the season represented different years, for the purpose of encompassing multiple calibration datasets in one model run:

- July 1 – August 31: 2007
- September 1 – September 19: 2012
- September 20 – September 30: 1987

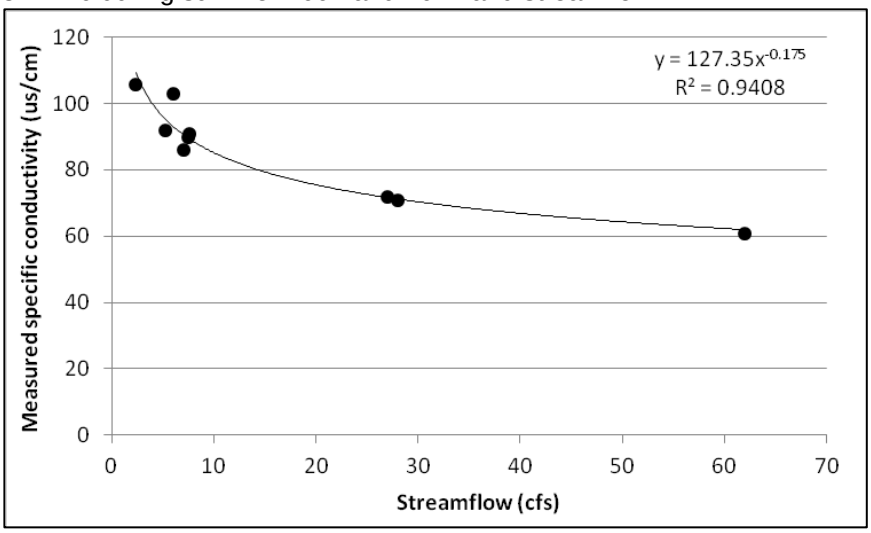
One disadvantage of this technique is that final conditions for one time period form the initial conditions of the next. This means that model predictions at the beginning of September still somewhat reflect 2007 conditions, and model conditions starting at September 20th still somewhat reflect 2012 conditions. The reason this is not a problem is that the model has 10-18 days to equilibrate after each date change before comparison to observed data. It was confirmed during model calibration that this is sufficient.

This "hybrid year" model was only used for calibration purposes to find the appropriate values for the rate variables. For determining loading capacity and allocations, a different version of the model was used, representing only 2007, which was a critical low-flow year.

Tables C-3, C-4, and C-5 summarize the boundary condition inputs for the QUAL2Kw model of the North Fork Palouse River.

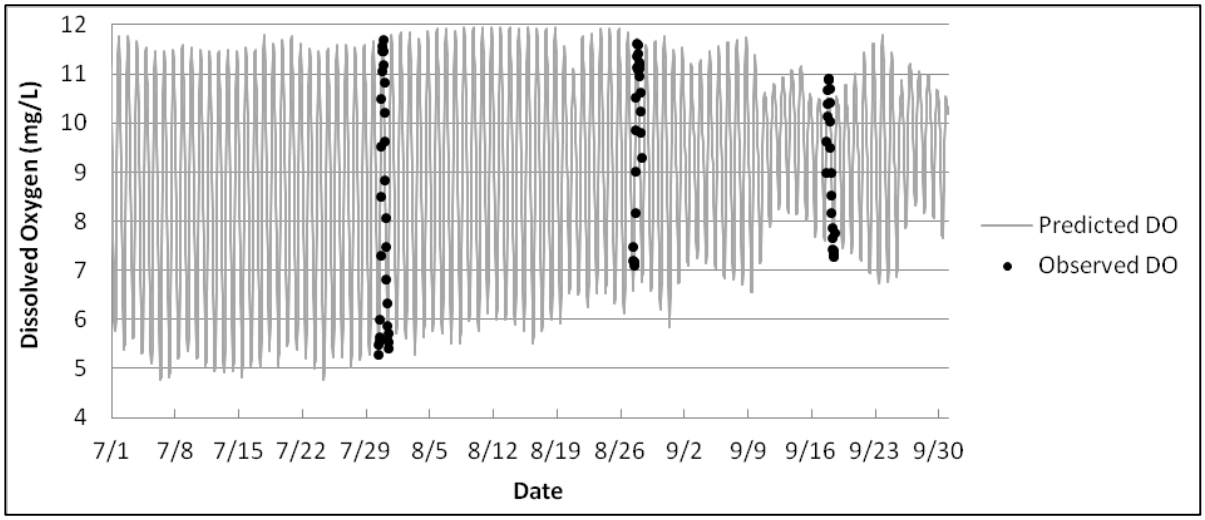
Table C-3. Headwater boundary model inputs for the main channel.

Note: This model is insensitive to upstream boundary conditions for temperature, dissolved oxygen, and pH, because the stream velocity is very slow. Regardless of the boundary input used, the model output for these constituents will equilibrate to reflect local in-stream processes within just a few model segments downstream. Methods were used for each parameter to provide the most realistic upper boundary inputs for these three constituents, given the available data.

Constituent	Input value or time-series, data source, and/or rationale
Streamflow	Flow data from USGS gaging station at Potlatch, ID. Because the boundary condition of the model is located 7 mi downstream of the gaging station, a time-delay of 19 hours was applied to all data at flows of less than 10 cfs (0.283 cms).[2]
Temperature	For 2007: Continuous water temperature data recorded at WA/ID state line (34PAL124.3) For 2012 and 1987: Output of rTemp (Pelletier, 2004) model for current vegetation conditions at Bridge St. (34PAL120.3; Snouwaert and Stuart, 2013).
Conductivity	Continuous estimate of conductivity based on regression between recorded conductivity values at 34A170 during summer 2007 and 2012 and streamflow: 
Inorganic Suspended Solids	Used **0 mg/L** at all times. All Total Non-Volatile Suspended Solids results at 34PAL124.3 were non-detects.

(continued)

[2] Just as water takes time to move downstream, so changes in flow also take time to move downstream. However, the velocity (called "celerity") at which changes in flow move downstream is faster than the velocity at which the water itself moves downstream (Chapra, 1997). The principle is similar to the way in which waves in the ocean travel without the water itself traveling. Apparently the celerity of the North Fork Palouse River at low flow is such that it takes about 19 hours for changes in flow to transmit from the USGS gage at Potlatch to the WA/ID state line.

Dissolved Oxygen	Continuous estimate of dissolved oxygen based on a quasi-empirical model. The model is based on: 1.) the typical DO %saturation observed at 34PAL124.3 for each hour of the day during diel hydrolab deployments; 2.) The saturation point of the water, calculated from water temperature, conductivity, and site elevation using USGS methodology (USGS, 2011); and 3.) a correction to account for the observed trend that the magnitude of diel swings increases with at higher temperatures, presumably because of temperature effect on periphyton growth and respiration. 
Slow Carbonaceous Oxygen Demand	Used **11.481 mg/L** at all times. This is calculated as 4.3 * 2.67, where 4.3 mg/L is the average dissolved organic carbon (DOC) measurement at 34PAL124.3 during the August synoptic, and 2.67 is the stoichiometric ratio for oxidation of carbonaceous material.
Fast Carbonaceous Oxygen Demand	Used **0 mg/L** at all times. All carbonaceous material at the state line (34PAL124.3) was assumed to be slow-reacting.
Organic Nitrogen	For 2007 and 2012: Calculated as TPN-NH_4-NO_3. Linear interpolation across time between ambient data collected at Bridge St. (34A170) For 1987: Used **150 ug/L** at all times. Guess that reflects Total N values similar to 2007 and 2012 data; no TPN data was collected during 1987. (Note that DO and pH predictions are not sensitive to this constituent.)
Ammonia Nitrogen	For 2007 and 2012: Used **1 ug/L** at all times. All recorded NH_4 values at 34PAL124.3 and most summertime values at 34A170 are non-detects. For 1987: Used **25 ug/L** at all times, based on data from receiving water study.
Nitrate Nitrogen	Used **0 ug/L** at all times. All recorded NO2-NO3 values at 34PAL124.3, all summertime values at 34A170 during 2007 and 2012, and all values recorded near the state line during the receiving water study are non-detects.
Organic Phosphorus	For 2007 and 2012: Calculated as TP minus OP. Linear interpolation across time between ambient data collected at Bridge St. (34A170). For 1987: Used **20 ug/L** at all times, based on TP data from receiving water study and assumption that ratio of inorganic to organic P was similar to 2007. (Note that modeling showed that DO and pH predictions are not sensitive to this constituent.)
Inorganic Phosphorus	For 2007 and 2012: Linear interpolation across time between ambient orthophosphate (OP) data collected at Bridge St. (34A170). For 1987: Used **10 ug/L** at all times, based on TP data from receiving water study and assumption that ratio of inorganic to organic P was similar to 2007.
Detritus	Used **1.6875 mg/L** at all times. This is calculated as 0.675 * 2.5, where 0.675 is the average particulate organic carbon (POC) during the August synoptic, which is calculated as TOC-DOC, and 2.5 is the stoichiometric ratio of dry weight to carbon.

(continued)

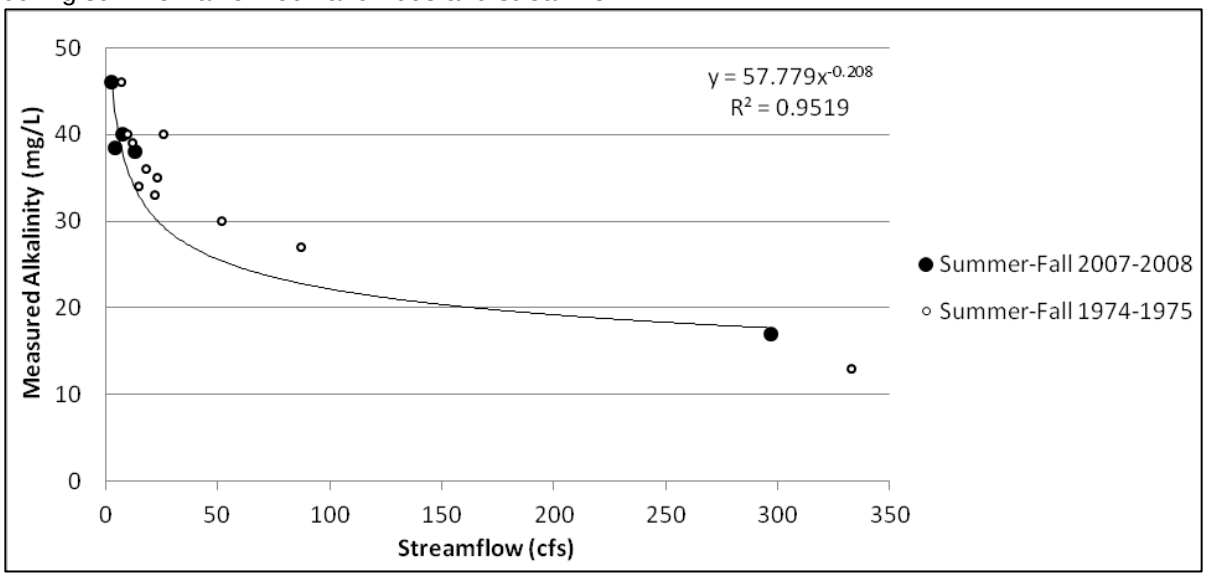
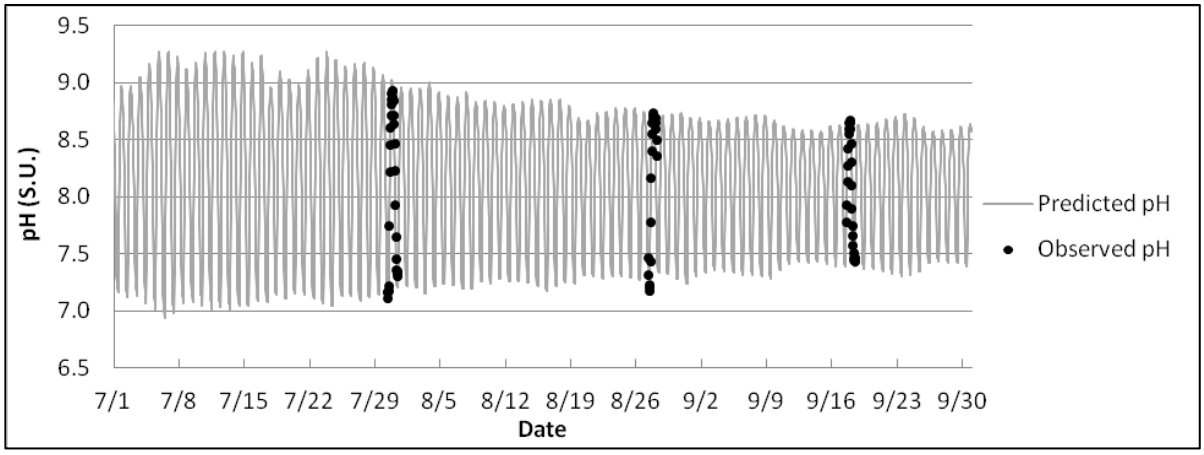
Pathogen Generic	(constituents not used)
Alkalinity	Continuous estimate of alkalinity based on regression between recorded alkalinity values at 34A170 during summer-fall of 2007 and 2008 and streamflow:  *Note: The ambient monitoring program collected alkalinity data at 34A170 only during 2007-2008 and 1974-1975. The 1974-1975 data are shown on the above plot for comparison, but were not considered in the regression. Spring and winter data are not shown and were not considered.*
pH	Continuous estimate of pH based on an empirical model. The model is based on: 1.) the typical pH value observed at 34PAL124.3 for each hour of the day during diel hydrolab deployments; and 2.) a correction to account for the observed trend that the magnitude of diel swings increases with at higher temperatures, presumably because of temperature effect on periphyton growth and respiration. 

Table C-4. Model inputs for Palouse WWTP effluent discharge.

Unless otherwise indicated, inputs for 2007 and 2012 represent the average values from 24-hour composite samples taken during July and August synoptic surveys in 2007, and inputs for 1987 are taken from receiving water study data. The current wastewater treatment plant was built in 1995; the 1987 data represent a previous plant.

Constituent	Input value or time-series, data source, and/or rationale
Effluent flow	For 2007 and 2012: For each month, the average daily effluent flow from that month for the last three years was averaged. This average flow for each month was assumed to apply on the 15th of that month, and linear interpolation across time was used from the 15th of one month to the 15th of the next. For 1987: Used **0.13 cfs (0.00368 cms)** at all times.
Temperature	For 2007 and 2012: Continuous effluent temperature data For 1987: Used **18.23°C** at all times.
Conductivity	For 2007 and 2012: **677 uS/cm** For 1987: **851.3 uS/cm**
Inorganic Suspended Solids	**0.5 mg/L**
Dissolved Oxygen	For 2007 and 2012: **6.0 mg/L** For 1987: **2.59 mg/L**
Slow Carbonaceous Oxygen Demand	**0 mg/L.** All carbonaceous material in the WWTP effluent is classified as fast-reacting.[3]
Fast Carbonaceous Oxygen Demand	For 2007 and 2012: **18.75 mg/L**. Calculated as 7.025 * 2.67 where 7.025 mg/L is the average dissolved organic carbon (DOC) measurement at 34PALWTP during both synoptics, and 2.67 is the stoichiometric ratio for oxidation of carbonaceous material. For 1987: **108.5 mg/L**. Calculated as 24/(1-e^(-0.05*5)) where 24 is the BOD5 result from the receiving water study, 0.05 is a reasonable BOD decay rate for a primary treatment facility[4] (see Cusimano, 2003; Appendix B, Table B4, Liberty Lake POTW), and 5 is the 5 days of the BOD5 test (Pelletier and Chapra, 2008).
Organic Nitrogen	For 2007 and 2012: **1075 ug/L**. Calculated as (TPN-NH_4-NO_3). For 1987. **0 ug/L**. No TPN data was collected during 1987, assume that all N was inorganic.[5]
Ammonia Nitrogen	For 2007 and 2012: **59 ug/L** For 1987: **11420 ug/L**
Nitrate Nitrogen	For 2007 and 2012: **32425 ug/L** For 1987: **9700 ug/L**
Organic Phosphorus	For 2007 and 2012: **823 ug/L**. Calculated as TP-OP. For 1987: **932 ug/L**. No orthophosphate (OP) data was collected during 1987, assume that TP/OP ratio was same in 1987 as in 2007.[5]
Inorganic Phosphorus	For 2007 and 2012: **5802 ug/L**. For 1987: **6908 ug/L.** No orthophosphate (OP) data was collected during 1987, assume that TP/OP ratio was same in 1987 as in 2007.

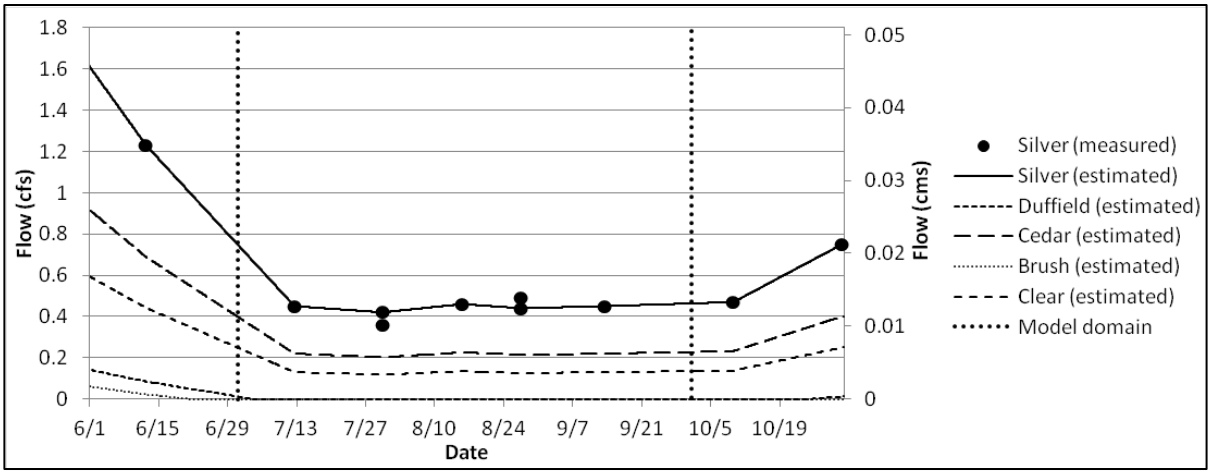
(continued)

[3] This allows for separate accounting of carbon from the WWTP and from other sources. If necessary, it also allows for different oxidation rates for each.
[4] Palouse WWTP was a primary treatment (trickling filter) facility in 1987. The current facility was built in 1995.
[5] The model is not very sensitive to the amount of organic nitrogen, or organic phosphorus.

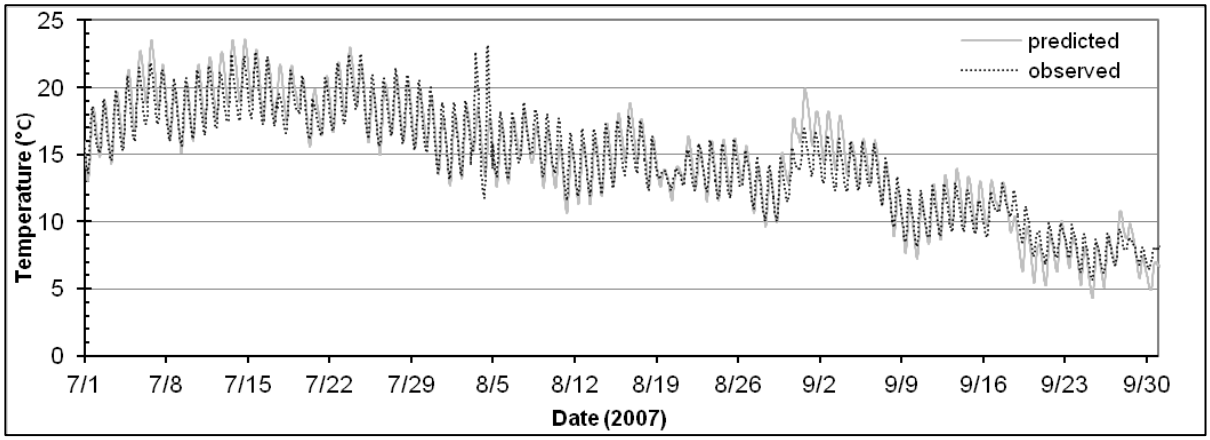
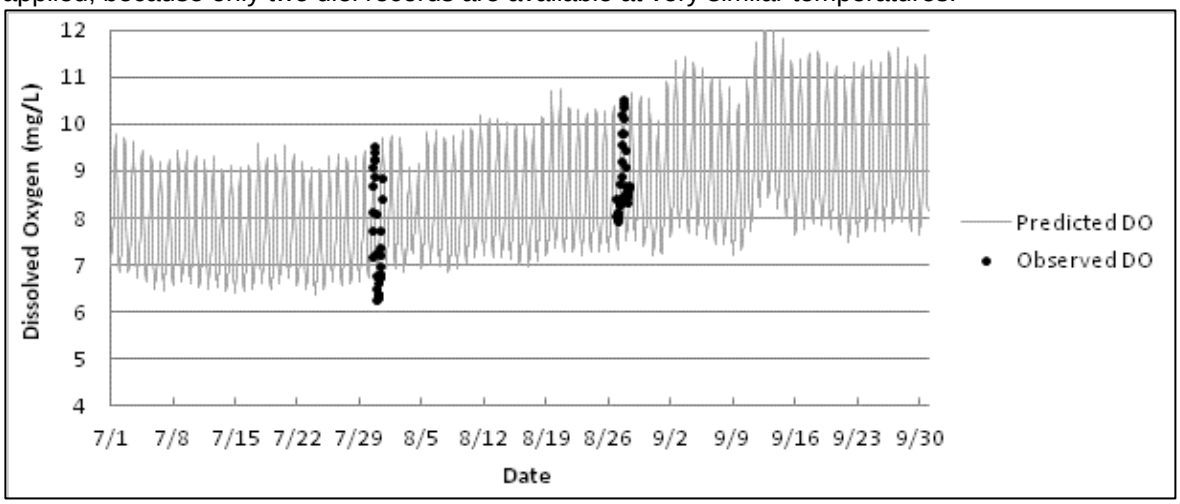
Detritus	For 2007 and 2012: **0.625 mg/L.** Calculated as 0.25 * 2.5 where 0.25 mg/L is the average particulate organic carbon (POC) during both synoptics, which is calculated as TOC-DOC, and 2.5 is the stoichiometric ratio of dry weight to carbon. For 1987: **0.625 mg/L.** No data, so assume same as 2007.
Pathogen	(constituents not used)
Generic	
Alkalinity	For 2007 and 2012: **97.7 mg/L.** For 1987: **97.7 mg/L**. No data, so assume same as 2007.
pH	For 2007 and 2012: **6.985 S.U.** For 1987: **7.6 S.U.**

Table C-5. Model inputs for tributaries.

Unless otherwise indicated, inputs represent the average of samples taken at Silver Creek at the mouth (34SIL00.0) during the two synoptics in 2007. The same data are used for 2012 and 1987, since no tributary data were collected during those years. The same water quality inputs are used for all tributaries.

Constituent	Input value or time-series, data source, and/or rationale
Streamflow	For Silver Ck.: Continuous estimate based on linear interpolation between flow measurements, excluding outliers which would create unrealistic spurious jumps. For all other tributaries: Estimate based on Silver Creek data, watershed area, and topography. 

(continued)

Temperature	For 2007: Continuous water temperature data recorded at Silver Ck. at mouth (34SIL00.0). For 2012 and 1987: Continuous estimate of water temperature using rTemp (Pelletier, 2004) model calibrated to 34SIL00.0 data from 2007: 
Conductivity	**262 uS/cm**
Inorganic Suspended Solids	**5 mg/L.** The two data points for this constituent were 10 mg/L during July and 4 mg/L during August. Used a lower-end estimate.
Dissolved Oxygen	Continuous estimate of dissolved oxygen based on a quasi-empirical model. The model is based on: 1.) the typical DO %saturation observed at 34SIL00.0 for each hour of the day during diel hydrolab deployments; 2.) The saturation point of the water, calculated from water temperature, conductivity, and site elevation using USGS methodology (USGS, 2011). No additional correction for diel range is applied, because only two diel records are available at very similar temperatures. 
Slow Carbonaceous Oxygen Demand	**3.938 mg/L**. Calculated as 1.475 * 2.67 where 1.467 mg/L is the average dissolved organic carbon (DOC) measurement at 34SIL00.0 during both synoptics, and 2.67 is the stoichiometric ratio for oxidation of carbonaceous material.
Fast Carbonaceous Oxygen Demand	**0 mg/L**. All carbonaceous material was classified as slow-reacting.
Organic Nitrogen	**121 ug/L.** Calculated as TPN-NH_4-NO_3.

(continued)

Ammonia Nitrogen	**8.25 ug/L**
Nitrate Nitrogen	**25.5 ug/L**
Organic Phosphorus	**37.8 ug/L**. Calculated as TP-OP.
Inorganic Phosphorus	**123 ug/L**
Detritus	**1.56 mg/L**. Calculated as 0.625 * 2.5 where 0.625 mg/L is the average particulate organic carbon (POC) during both synoptics, which is calculated as TOC-DOC, and 2.5 is the stoichiometric ratio of dry weight to carbon.
Pathogen	(constituents not used)
Generic	
Alkalinity	**141.5 mg/L**
pH	**7.75 S.U.**

Initial Conditions

Table C-6. Initial condition inputs.

Parameter	Initial condition input
Periphyton (biomass)	8 gD/m^2
Periphyton (intracellular N)	40 mgN/gD
Periphyton (intracellular P)	10 mgP/gD
Macrophyte (biomass)	Entered in ug/L, because Macrophytes were simulated by adapting QUAL2Kw's phytoplankton model. To normalize areal biomass for depth, the concentration input is calculated as: $$\frac{C}{D * \frac{S_d}{S_a * 1000}} * I$$ Where: C = macrophyte carrying capacity D = model segment depth calculated for 8/27/07 $S_d/(S_a * 1000)$ = stoichiometric ratio of dry weight to chlorophyll I = portion of carrying capacity for initial conditions user rate input
All other parameters	Initial conditions for entire model domain set to upstream boundary condition input at the first time step

Climate and Shade Inputs

Table C-7. Data sources for climate and shade model inputs

Parameter	Data Source
Air temperature	National Weather Service/Pullman-Moscow Regional Airport
Dew point	National Weather Service/Pullman-Moscow Regional Airport
Windspeed	National Weather Service/Pullman-Moscow Regional Airport, modified by wind sheltering factor of 0.3
Cloud cover	National Weather Service/Pullman-Moscow Regional Airport
Solar radiation	Calculated internally using Ryan-Stolzenbach model, atmospheric transmission factor = 0.8
Shade	Used shade model results from Palouse River Temperature TMDL (Snouwaert and Stuart, 2013)

Rate Parameters

Table C-8. QUAL2Kw Rate Parameters

Parameter	Value
Stoichiometry	
Carbon	40 gC
Nitrogen	7.2 gN
Phosphorus	1 gP
Dry weight	100 gD
Chlorophyll	0.3 gA
Inorganic suspended solids	
Settling velocity	0.3 m/d
Oxygen	
Reaeration model	User model (A * velocity^B * depth ^C)
User reaeration model parameter A	4.482
User reaeration model parameter B	0.64
User reaeration model parameter C	-1.665
Temp correction for reaeration	1.024
Reaeration wind effect	Banks-Herrera
O2 for carbon oxidation	2.67 gO_2/gC
O2 for NH4 nitrification	4.57 gO_2/gN
Oxygen inhib model CBOD oxidation	Exponential
Oxygen inhib parameter CBOD oxidation	0.60 L/mgO_2
Oxygen inhib model nitrification	Exponential
Oxygen inhib parameter nitrification	0.60 L/mgO_2
Oxygen enhance model denitrification	Exponential
Oxygen enhance parameter denitrification	0.60 L/mgO_2
Oxygen inhib model phyto resp	Exponential
Oxygen inhib parameter phyto resp	0.60 L/mgO_2
Oxygen enhance model bot alg resp	Exponential
Oxygen enhance parameter bot alg resp	0.60 L/mgO_2
Slow CBOD	
Hydrolysis rate	0 /d
Oxidation rate	0 /d
Fast CBOD	
Oxidation rate	0 /d; 0.075 /d; or 0.066 /d [6]
Organic N	
Hydrolysis	0.0019 /d
Temp correction	1.07
Settling velocity	0 m/d
Ammonium	
Nitrification	0.05 /d
Temp correction	1.07

(continued)

[6] Any effect of BOD oxidation on DO downstream of Palouse WWTP was small enough to be lost in the "noise" of data and/or model error. For purposes of calibrating the model, this rate parameter did not matter and 0 /d was used. To test potential impacts of BOD from Palouse WWTP, a theoretical rate of 0.075 /d was used (Chapra, 1997). To test potential impacts of BOD from nonpoint, a rate of 0.066 /d was used (Portland State University, 2011; Cusimano, 2003).

Parameter	Value
Nitrate	
Denitrification	1.71 /d
Temp correction	1.07
Sed denitrification transfer coeff	0.1 m/d
Temp correction	1.07
Organic P	
Hydrolysis	0.25 /d
Temp correction	1.07
Settling velocity	0 m/d
Inorganic P	
Settling velocity	0 m/d
Sed P oxygen attenuation half sat constant	1 mgO_2/L
Macrophytes[7]	
Max Growth rate	0.2 /d
Temp correction	1.07
Carrying capacity[8]	150 gD/m^2
Portion of carrying capacity for initial condition[9]	0.015
Respiration rate	0.015 /d
Temp correction	1.07
Death rate	0.015 /d
Temp correction	1
Nutrient limitation model for N and P	Minimum
Nitrogen half sat constant	0 ugN/L
Phosphorus half sat constant	0 ugP/L
Inorganic carbon half sat constant	0.0011 moles/L
Macrophytes use HCO3- as substrate	Yes
Light model	Half saturation
Light constant	41.3 langleys/d
Ammonia preference	25 ugN/L
Settling velocity	0 m/d
Include transport	No
Nitrogen uptake water column fraction	0.5
Phosphorus uptake water column fraction	0.5

(continued)

[7] Simulated as "phytoplankton" in the QUAL2Kw model framework. The version of QUAL2Kw used for this study contains some modifications to allow this, such as a carrying capacity, the ability to specify whether "phytoplankton" are transported downstream or not, and the ability to specify nutrient uptake from sediments.
[8] Specified using the "Bottom plants first order model carrying capacity" input. The version of the QUAL2Kw model used is programmed to use this input to regulate "phytoplankton" when "phytoplankton" transport is turned off.
[9] Specified as a user rate parameter. See initial conditions inputs section above.

Parameter	Value
Periphyton[10]	
Growth model	Zero-order
Max Growth rate	46.2 $gD/m^2/d$
Temp correction	1.07
Basal respiration rate	0.433 /d
Photo-respiration rate parameter	0
Temp correction	1.07
Excretion rate	0.00602 /d
Temp correction	1.07
Death rate	0.00095 /d
Temp correction	1.07
Scour function	(scour model not used)
External nitrogen half sat constant	431 ugN/L
External phosphorus half sat constant	178 ugP/L
Inorganic carbon half sat constant	0.000115 moles/L
Bottom algae use HCO3- as substrate	Yes
Light model	Half saturation
Light constant	73.4 langleys/d
Ammonia preference	5 ugN/L
Nutrient limitation model for N and P	Minimum
Subsistence quota for nitrogen	34.5 mgN/gD
Subsistence quota for phosphorus	4.79 mgP/gD
Maximum uptake rate for nitrogen	251 mgN/gD/d
Maximum uptake rate for phosphorus	50 mgP/gD/d
Internal nitrogen half sat ratio	2.08
Internal phosphorus half sat ratio	1.4
Nitrogen uptake water column fraction	1
Phosphorus uptake water column fraction	1
Detritus (particulate organic matter)	
Dissolution rate	0.1 /d
Temp correction	1.07
Settling velocity	0 m/d
pH	
Partial pressure of carbon dioxide	380 ppm
Photosynthetic quotient and respiratory quotient for periphyton and macrophytes	
Photosynthetic quotient for NO3 vs NH4 use	1.29
Respiratory quotient	1.00
The following constituents and functions in QUAL2Kw were not used: • *Pathogens* • *Generic constituent*[11] • *Hyporheic metabolism*	

[10] Simulated as "bottom plants" in QUAL2Kw.

[11] Not used in rate parameter calibration or scenario runs. The generic constituent did get used to simulate rhodamine dye in a specialized set of model runs to refine channel geometry. See plots for "Rhodamine dye / Time of Travel" in Model Goodness-of-Fit section below.

Model Goodness-of-Fit

The North Fork Palouse River QUAL2Kw model goodness of fit to observed data is summarized in Table C-9. The Root Mean Squared Error (RMSE) statistic expresses the magnitude of typical model error for a variable in the same units as that variable. The Root Mean Squared Error Coefficient of Variation (RMSE CV) expresses the proportion of typical model error to the typical value of the variable. The overall bias statistic expresses the tendency of the model to over- or under-predict the value of a given variable. Bias% expresses this tendency as a proportion of the typical value of the variable. The average observed values from this study for most variables are given for reference.

For most variables, RMSE and bias are calculated by comparing modeled daily average values to observed daily average or grab sample values. For variables that display a marked diel swing, such as temperature, dissolved oxygen, and pH, the RMSE and bias are calculated for daily maximums and minimums instead. RMSE CV and Bias%, which express error as a proportion of typical variable values, are given for those variables that express a quantity or concentration of something. These statistics are not appropriate for temperature or pH.

The QUAL2Kw model provides an excellent simulation of DO and pH in the North Fork Palouse River. In particular, daily minimum DO had a minimal amount of error (RMSE = 0.65 mg/L) and almost no bias (overall bias = +0.07 mg/L). Daily maximum pH also had a minimal amount of error (0.29 S.U.) and almost no bias (overall bias = +0.05 S.U.)[12]. The model also provides a good simulation of nutrient concentrations. However, swift nutrient uptake and slow travel times on the North Fork Palouse River mean that nutrient curves graphed as concentration vs. time tend to be very steep. This results in apparently high calculated error values for these parameters. The calibration plots presented below are better able to provide an indication of model quality for these fast-changing parameters than the error statistics can.

[12] Daily minimum DO and daily maximum pH are of particular importance because these are what get compared to the water quality standards for low DO and high pH.

Table C-9. Summary statistics for goodness-of-fit of the QUAL2Kw model to observed data.

Variable	RMSE			RMSE CV			Overall Bias			Bias %			Avg Obs Value		
	Daily Max	Daily Min	Daily Avg	Daily Max	Daily Min	Daily Avg	Daily Max	Daily Min	Daily Avg	Daily Max	Daily Min	Daily Avg	Daily Max	Daily Min	Daily Avg
Temperature (degC)*	2.23	1.15					+0.21	-0.22							
Temperature (degC)**	3.42	3.47					-1.79	-2.57							
Conductivity (uS/cm 25C)			11.1			9.9%			-2.4			-2.1%			113
Inorganic susp. solids (mgD/L)			0.99			87.6%			-0.78			-69%			1.13
Dissolved oxygen (mgO2/L)	1.49	0.65		12.1%	9.8%		-0.13	+0.07		-1.0%	+1.0%		12.29	6.58	
Organic N (ugN/L)			102.7			27.5%			+58.6			+15.7%			373.9
Ammonium N (ugN/L)***			42.3			148.3%			+5.5			+19.2%			28.5
Nitrate + nitrite N (ugN/L)***			122.6			148.4%			-25.9			-31.3%			82.6
Organic P (ugN/L)			5.1			26.3%			-2.3			-12.0%			19.6
Inorganic P (ugP/L)			11.4			56.8%			-5.1			-25.3%			20.1
Total N (ug/L)			157.3			36.4%			+9.3			+2.2%			432.5
Total P (ugP/L)			50.6			73.1%			+9.2			+13.4%			69.3
Alkalinity (mgCaCO3/L)			7.15			12.4%			-5.6			-9.7%			57.6
pH	0.29	0.61					+0.05	-0.29							
Total suspended solids (mgD/L)			1.2			62.0%			+0.3			+15.6%			2.0
Total organic C (mgC/L)			0.29			5.1%			-0.13			-2.2%			5.7
Dissolved organic C (mgC/L)			0.34			7.1%			-0.06			-1.3%			4.8

*Survey dates
**All dates July-August
***Uptake curves (graphed as concentration vs. longitudinal distance) for inorganic forms of nitrogen tend to be very steep. This results in apparently high RMSE values. However, the fit for these parameters is still considered good. See calibration plots of Ammonia and Nitrate-Nitrite below .

$$RMSE = \sqrt{\frac{\Sigma(T_{modeled} - T_{observed})^2}{n}}$$

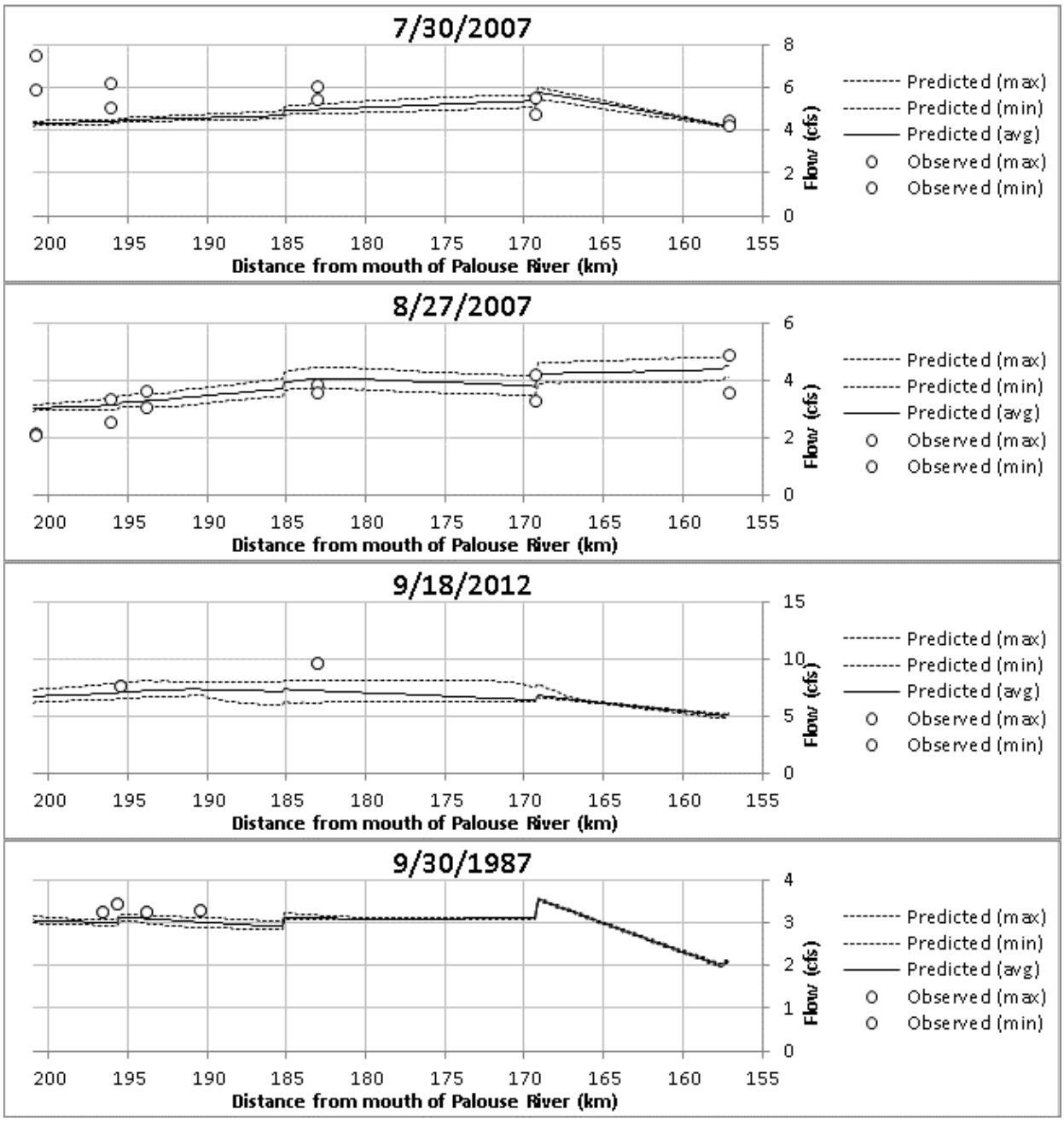
$$RMSE\ \ CV = \frac{RMSE}{Avg\ obs\ value}$$

$$Bias = \frac{\sum(T_{modeled} - T_{observed})}{n}$$

$$Bias\ \% = \frac{Bias}{Avg\ obs\ value}$$

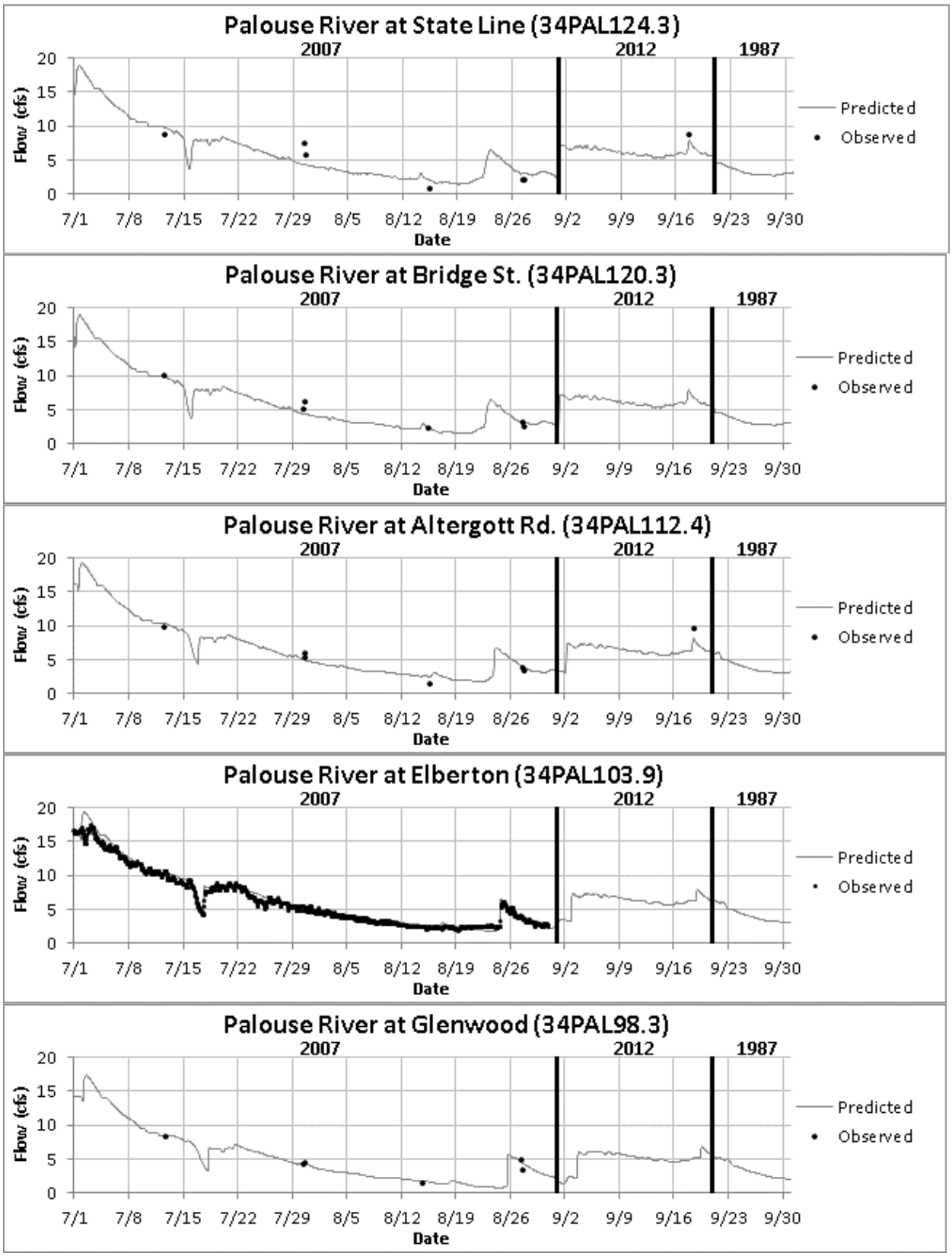
Figure C-2. Longitudinal, seasonal time-series, and (where applicable) diel plots of modeled vs. observed values for selected parameters *(this page plus the following 33 pages)*.

Streamflow[13] [14]

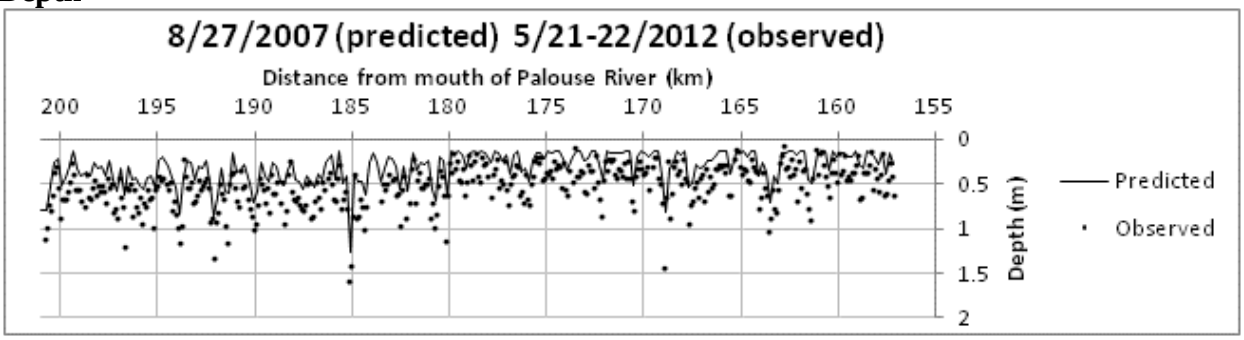


[13] Predicted and observed flows at the upstream end of the model domain do not match well because the upstream boundary condition input for flow is based on the USGS gage at Potlatch offset by 19 hours, and flow measurements taken at the upstream-most site (34PAL124.3) are considered to be of poor quality (RPD of duplicate flows = 17%; avg velocity of cross section during measurements = 0.03 ft/s).

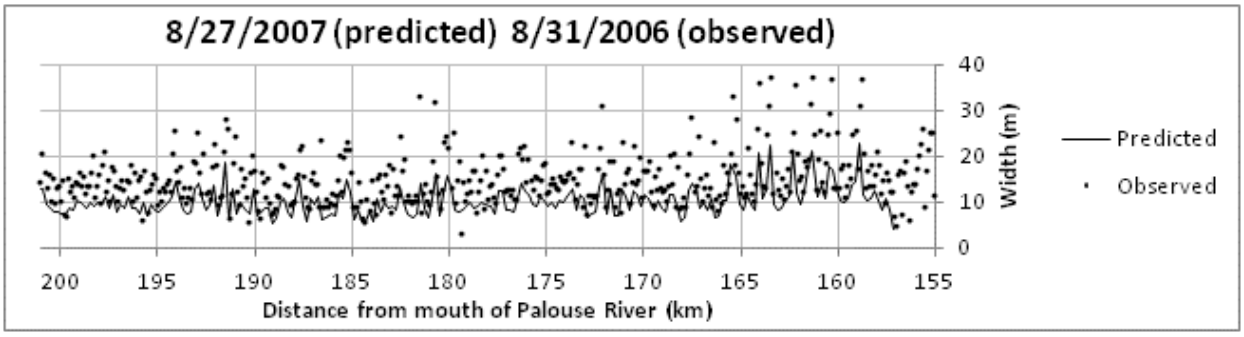
[14] QUAL2Kw simulates flow in cubic meters per second (cms). All flow plots are presented in cubic feet per second (cfs) for ease and familiarity, as measured and gaged flows in the U.S. are generally reported in cfs.


Palouse River at State Line (34PAL124.3)
Palouse River at Bridge St. (34PAL120.3)
Palouse River at Altergott Rd. (34PAL112.4)
Palouse River at Elberton (34PAL103.9)
Palouse River at Glenwood (34PAL98.3)
2007
2012
1987
Flow (cfs)
Date
Predicted
Observed
0
5
10
15
20
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

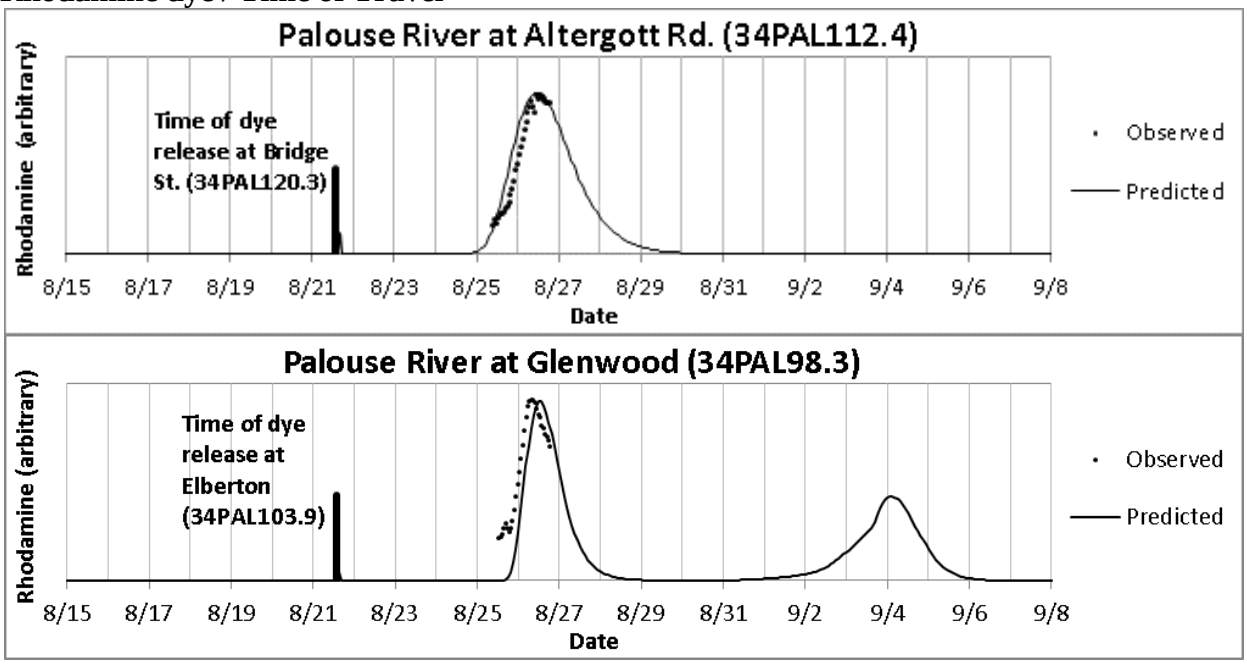
Depth[15]



Width[16]



Rhodamine dye / Time of Travel[17]

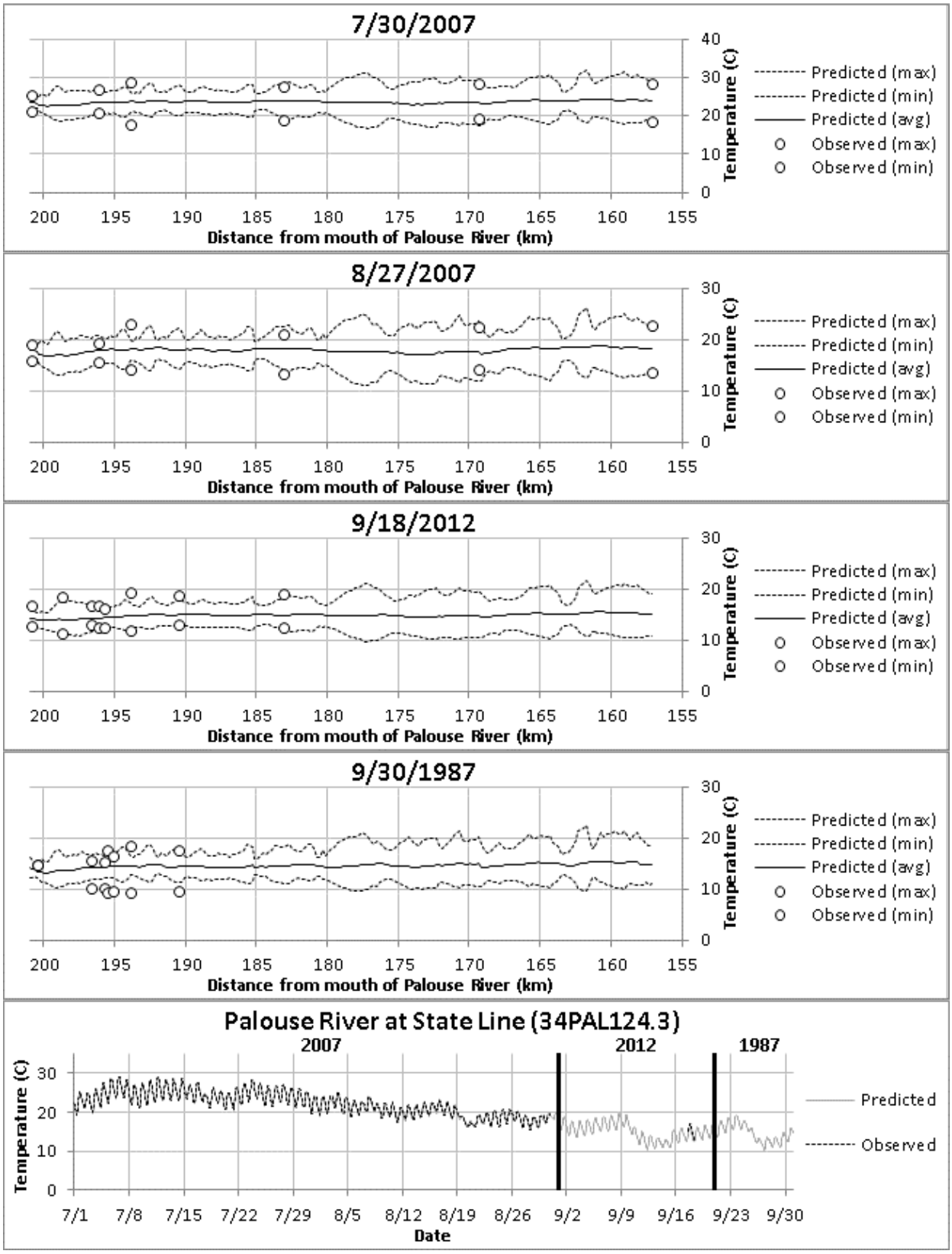


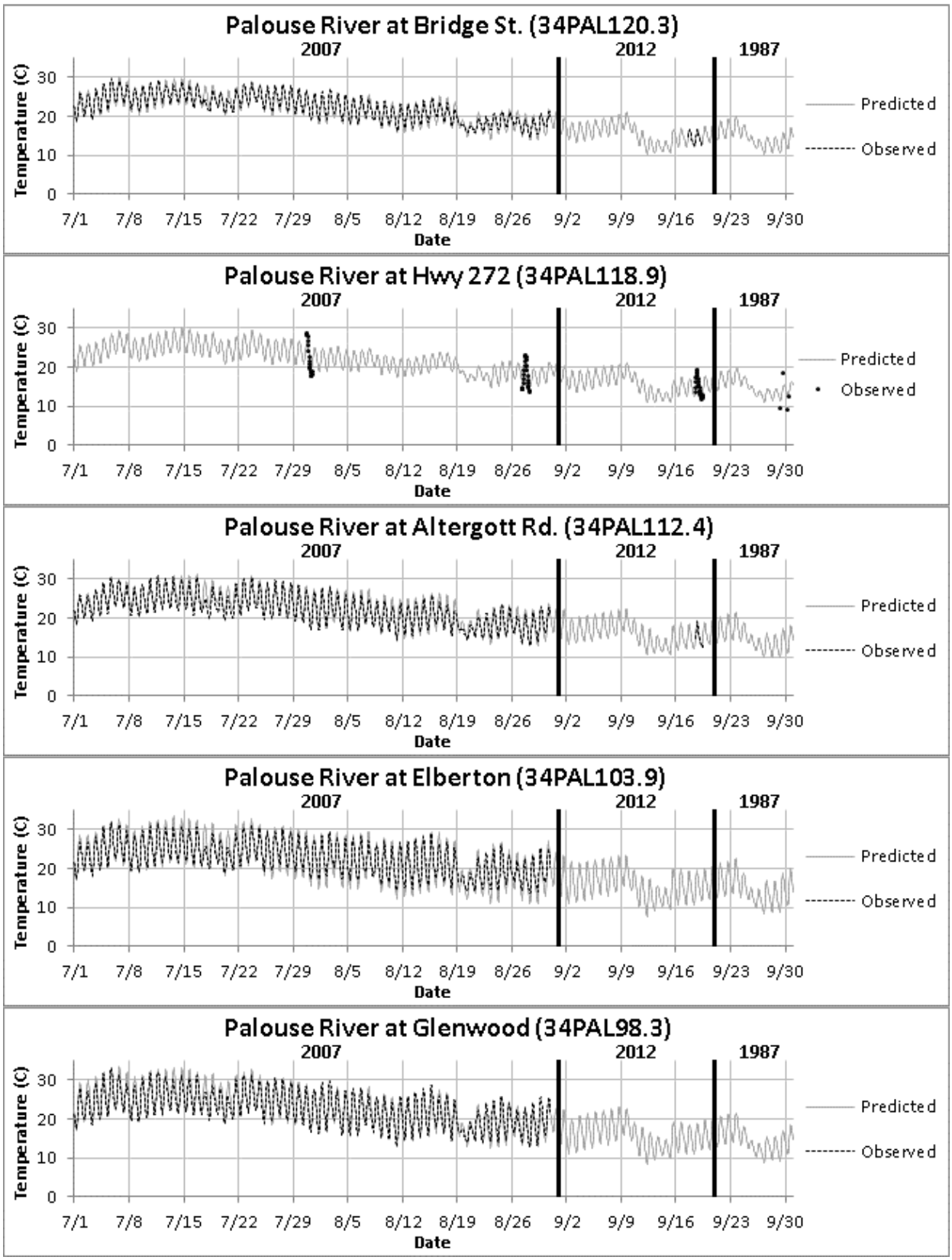
[15] At the time of the depth survey, streamflows were ~150 cfs. On 8/27/2007, streamflows were ~4 cfs. This is the reason why predicted depths are less than observed depths in this plot.

[16] A functional depth multiplier of 68% was applied to wetted widths measured from 8/31/2006 orthophotos. This is the reason why predicted widths are less than observed widths in this plot.

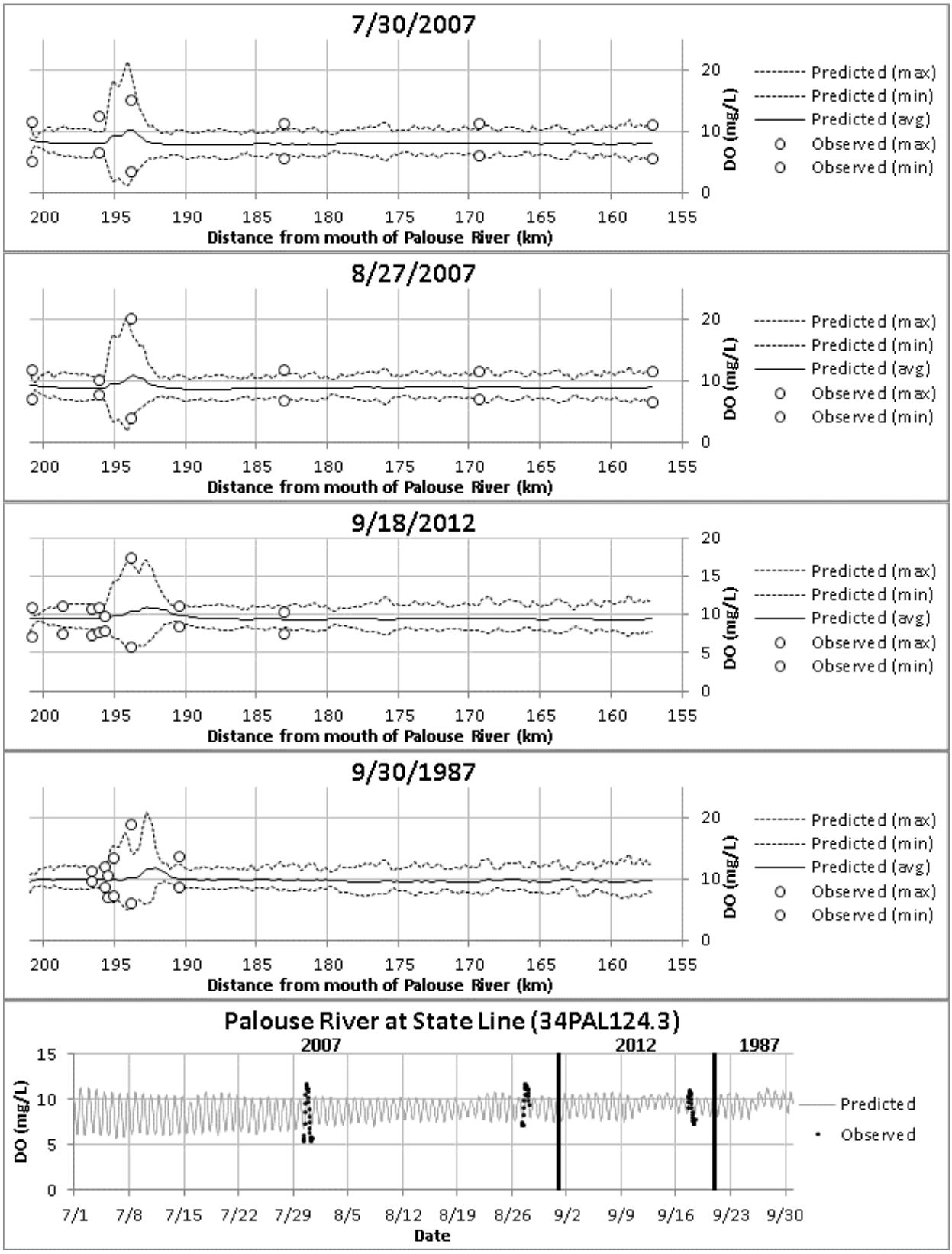
[17] Rhodamine probes were not calibrated, therefore rhodamine predictions are given in arbitrary units. The sizes of the dye releases in the model simulation were adjusted to match observed values. Timing and dispersion, not overall concentration, are the important elements. Dye was simulated using the user-defined generic constituent.

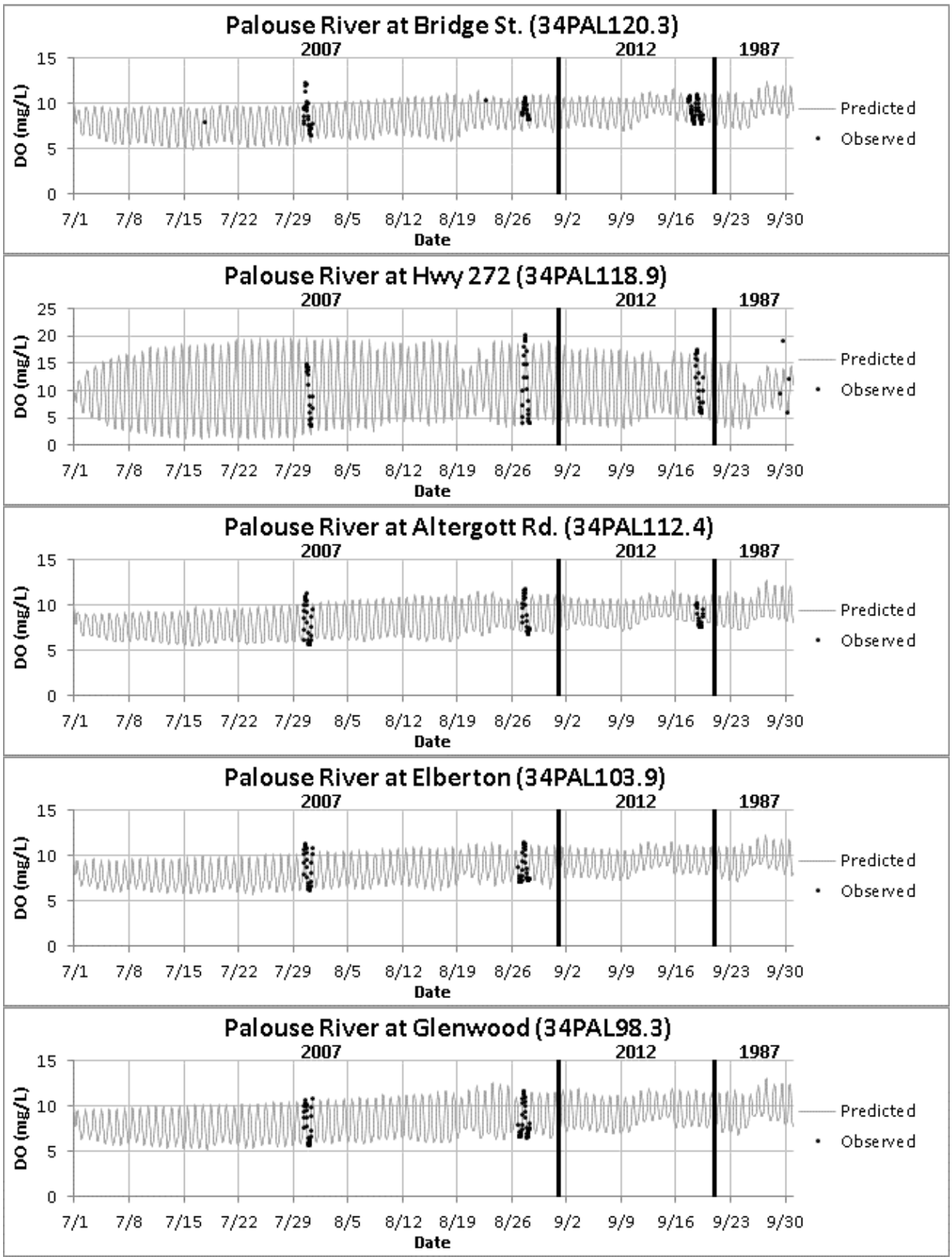
Temperature

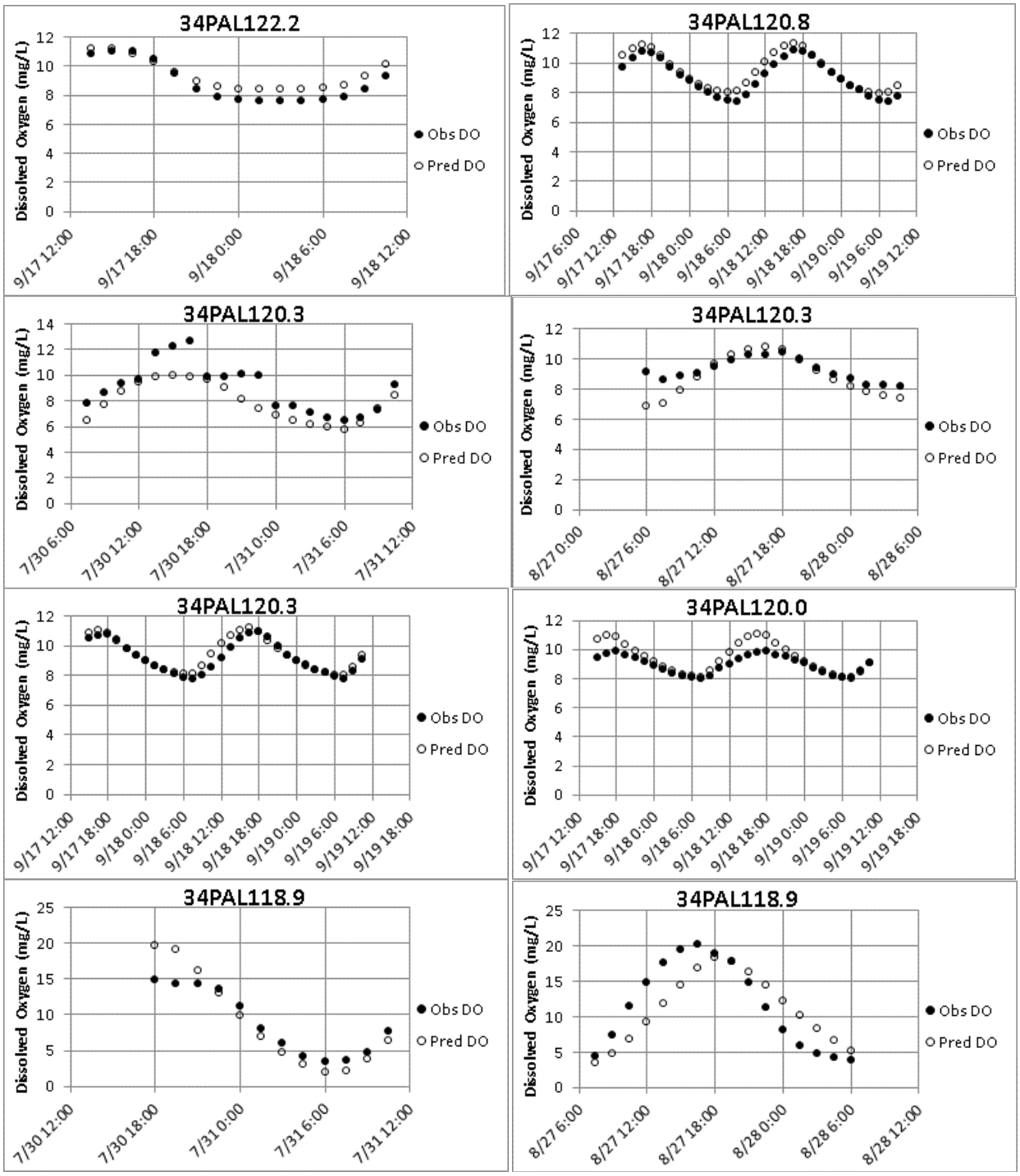


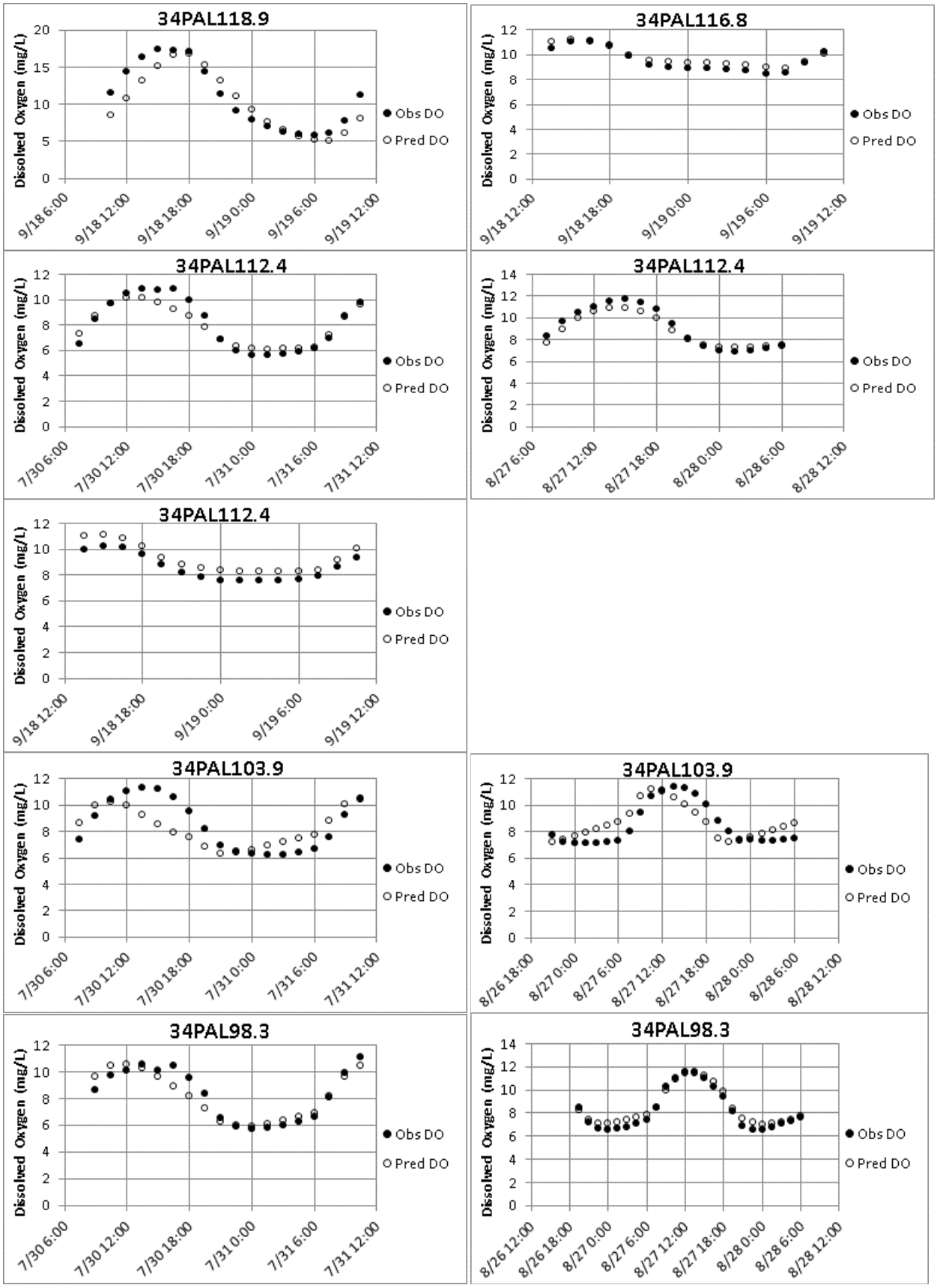

Palouse River at Bridge St. (34PAL120.3)
2007
2012
1987
Temperature (C)
Date
Predicted
Observed
Palouse River at Hwy 272 (34PAL118.9)
Palouse River at Altergott Rd. (34PAL112.4)
Palouse River at Elberton (34PAL103.9)
Palouse River at Glenwood (34PAL98.3)
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
0 10 20 30

Dissolved Oxygen

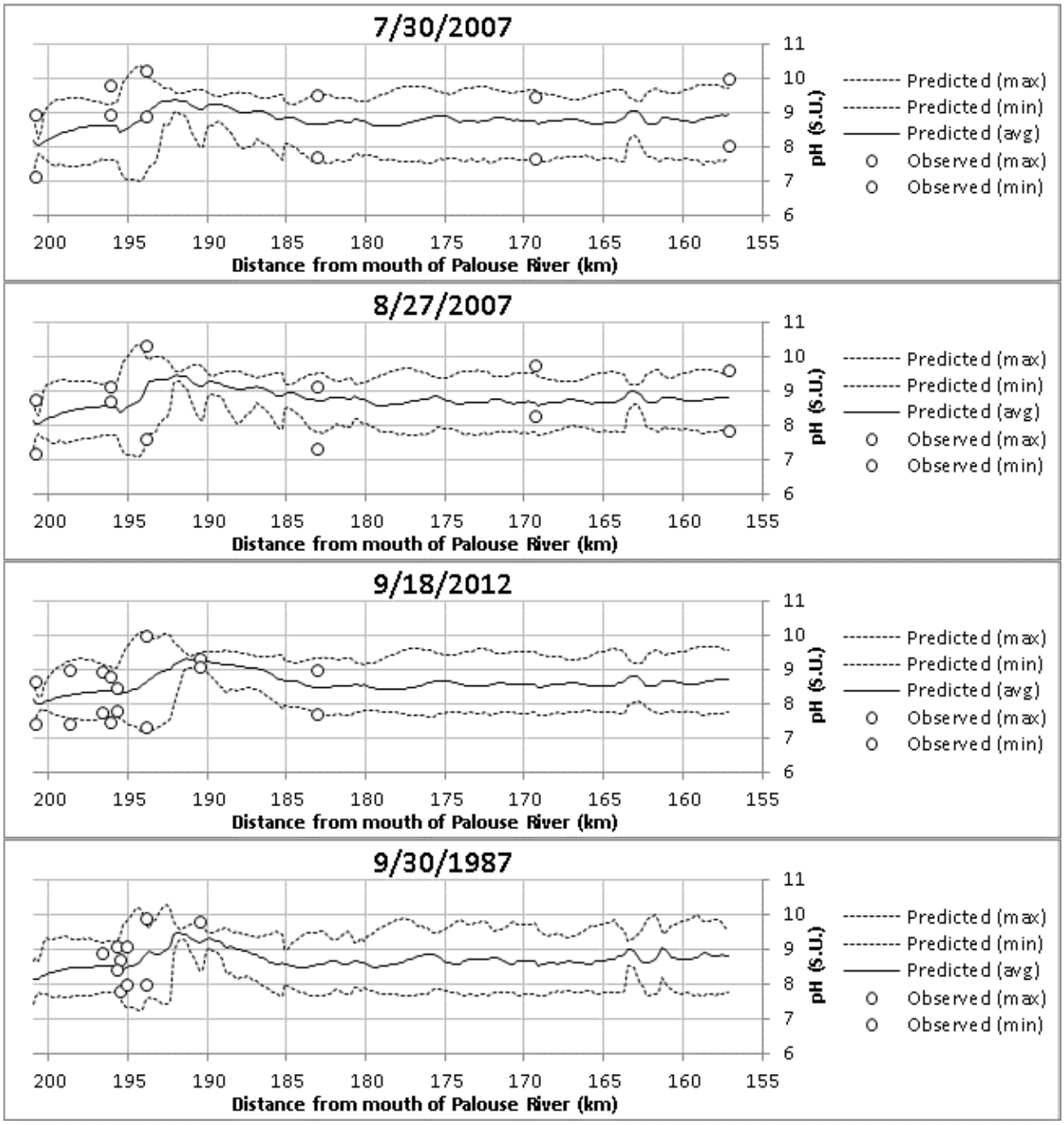



Palouse River at Bridge St. (34PAL120.3)
2007
2012
1987
DO (mg/L)
Date
Predicted
Observed
Palouse River at Hwy 272 (34PAL118.9)
Palouse River at Altergott Rd. (34PAL112.4)
Palouse River at Elberton (34PAL103.9)
Palouse River at Glenwood (34PAL98.3)
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30

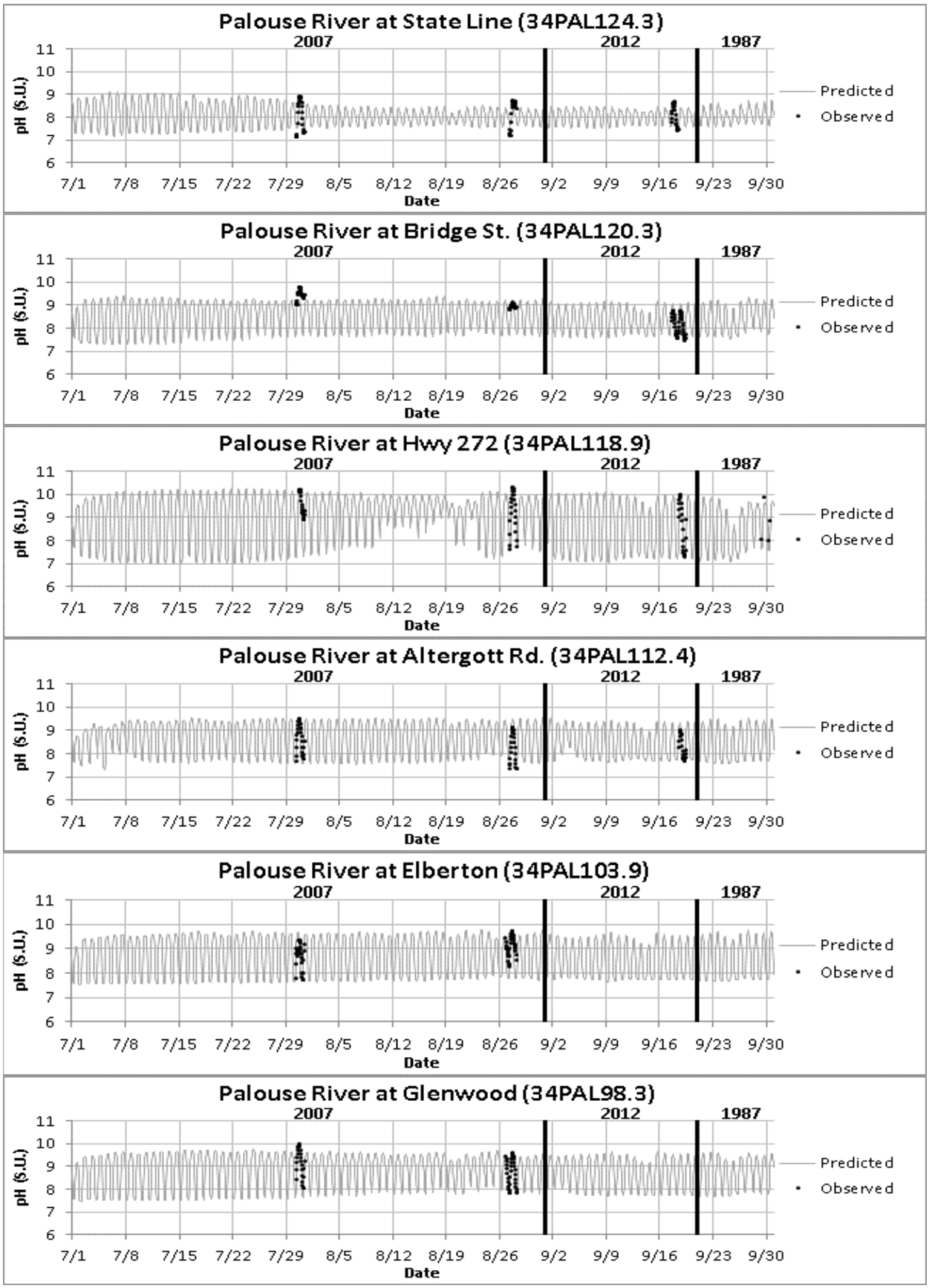

34PAL122.2
Dissolved Oxygen (mg/L)
Obs DO
Pred DO
9/17 12:00
9/17 18:00
9/18 0:00
9/18 6:00
9/18 12:00
34PAL120.8
Dissolved Oxygen (mg/L)
Obs DO
Pred DO
9/17 6:00
9/17 12:00
9/17 18:00
9/18 0:00
9/18 6:00
9/18 12:00
9/18 18:00
9/19 0:00
9/19 6:00
9/19 12:00
34PAL120.3
Dissolved Oxygen (mg/L)
Obs DO
Pred DO
7/30 6:00
7/30 12:00
7/30 18:00
7/31 0:00
7/31 6:00
7/31 12:00
34PAL120.3
Dissolved Oxygen (mg/L)
Obs DO
Pred DO
8/27 0:00
8/27 6:00
8/27 12:00
8/27 18:00
8/28 0:00
8/28 6:00
34PAL120.3
Dissolved Oxygen (mg/L)
Obs DO
Pred DO
9/17 12:00
9/17 18:00
9/18 0:00
9/18 6:00
9/18 12:00
9/18 18:00
9/19 0:00
9/19 6:00
9/19 12:00
9/19 18:00
34PAL120.0
Dissolved Oxygen (mg/L)
Obs DO
Pred DO
9/17 12:00
9/17 18:00
9/18 0:00
9/18 6:00
9/18 12:00
9/18 18:00
9/19 0:00
9/19 6:00
9/19 12:00
9/19 18:00
34PAL118.9
Dissolved Oxygen (mg/L)
Obs DO
Pred DO
7/30 12:00
7/30 18:00
7/31 0:00
7/31 6:00
7/31 12:00
34PAL118.9
Dissolved Oxygen (mg/L)
Obs DO
Pred DO
8/27 6:00
8/27 12:00
8/27 18:00
8/28 0:00
8/28 6:00
8/28 12:00

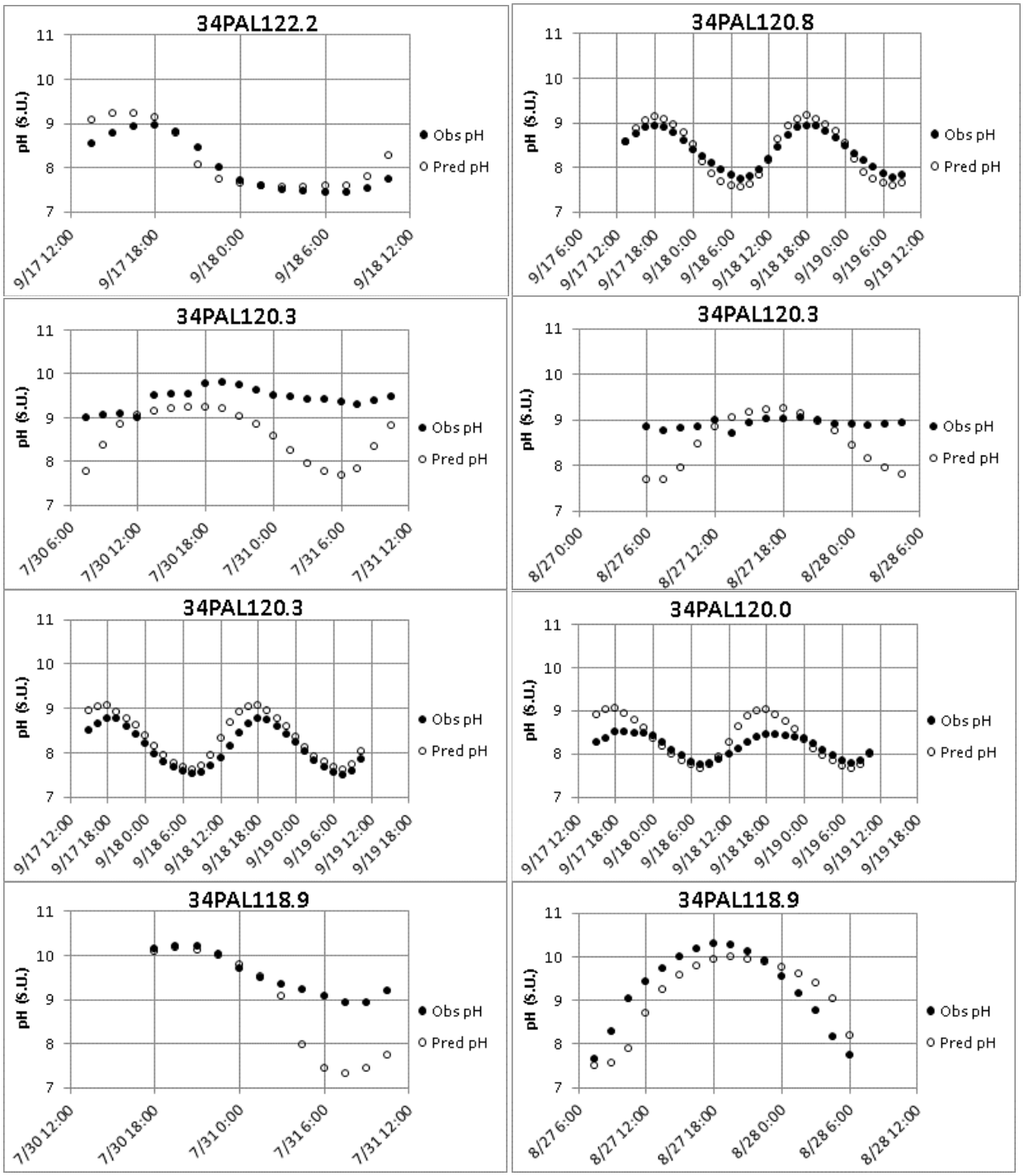

34PAL118.9
34PAL116.8
34PAL112.4
34PAL112.4
34PAL112.4
34PAL103.9
34PAL103.9
34PAL98.3
34PAL98.3
Dissolved Oxygen (mg/L)
Obs DO
Pred DO
9/18 6:00
9/18 12:00
9/18 18:00
9/19 0:00
9/19 6:00
9/19 12:00
7/30 6:00
7/30 12:00
7/30 18:00
7/31 0:00
7/31 6:00
7/31 12:00
8/26 12:00
8/26 18:00
8/27 0:00
8/27 6:00
8/27 12:00
8/27 18:00
8/28 0:00
8/28 6:00
8/28 12:00

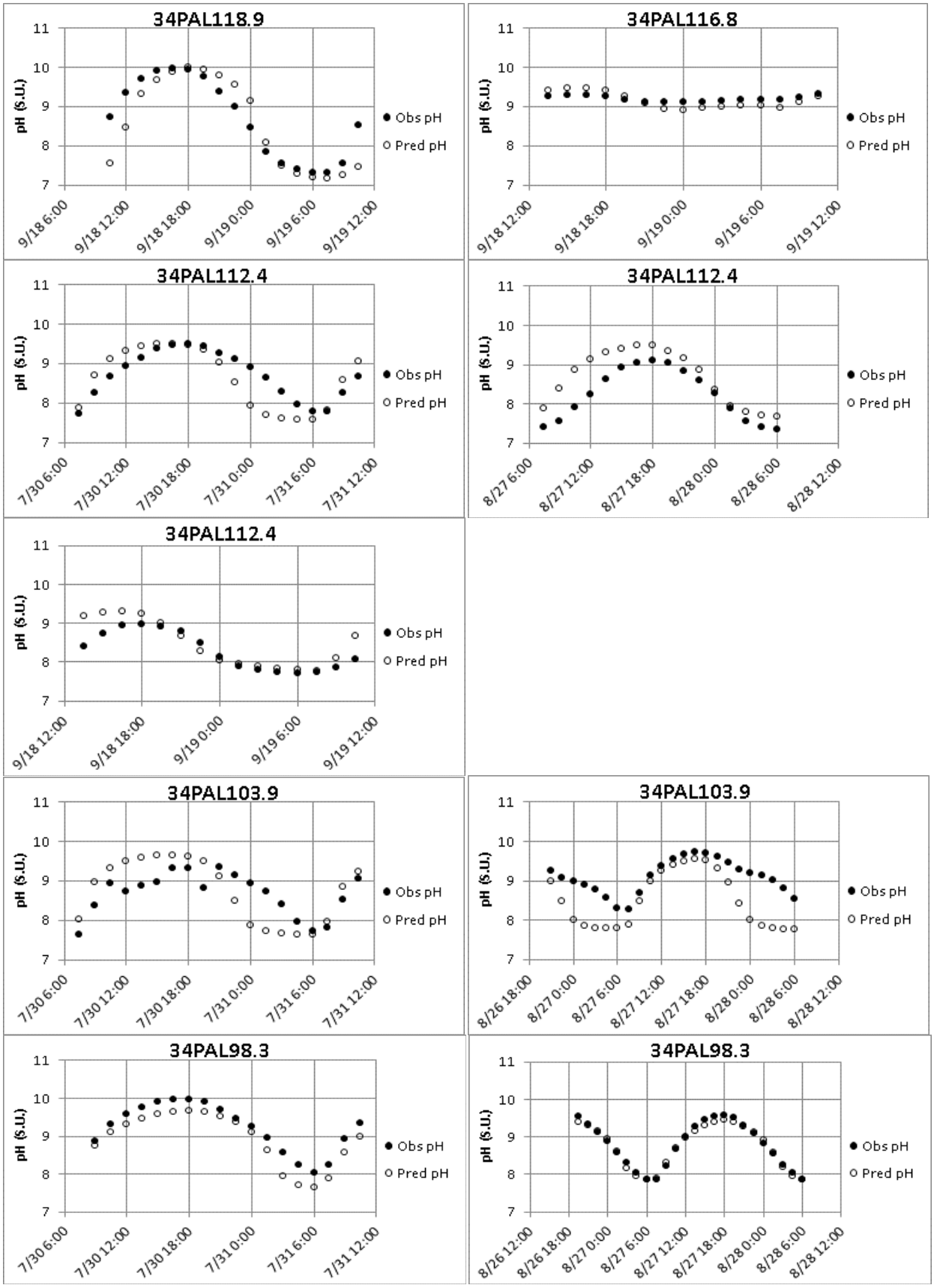
pH[18]



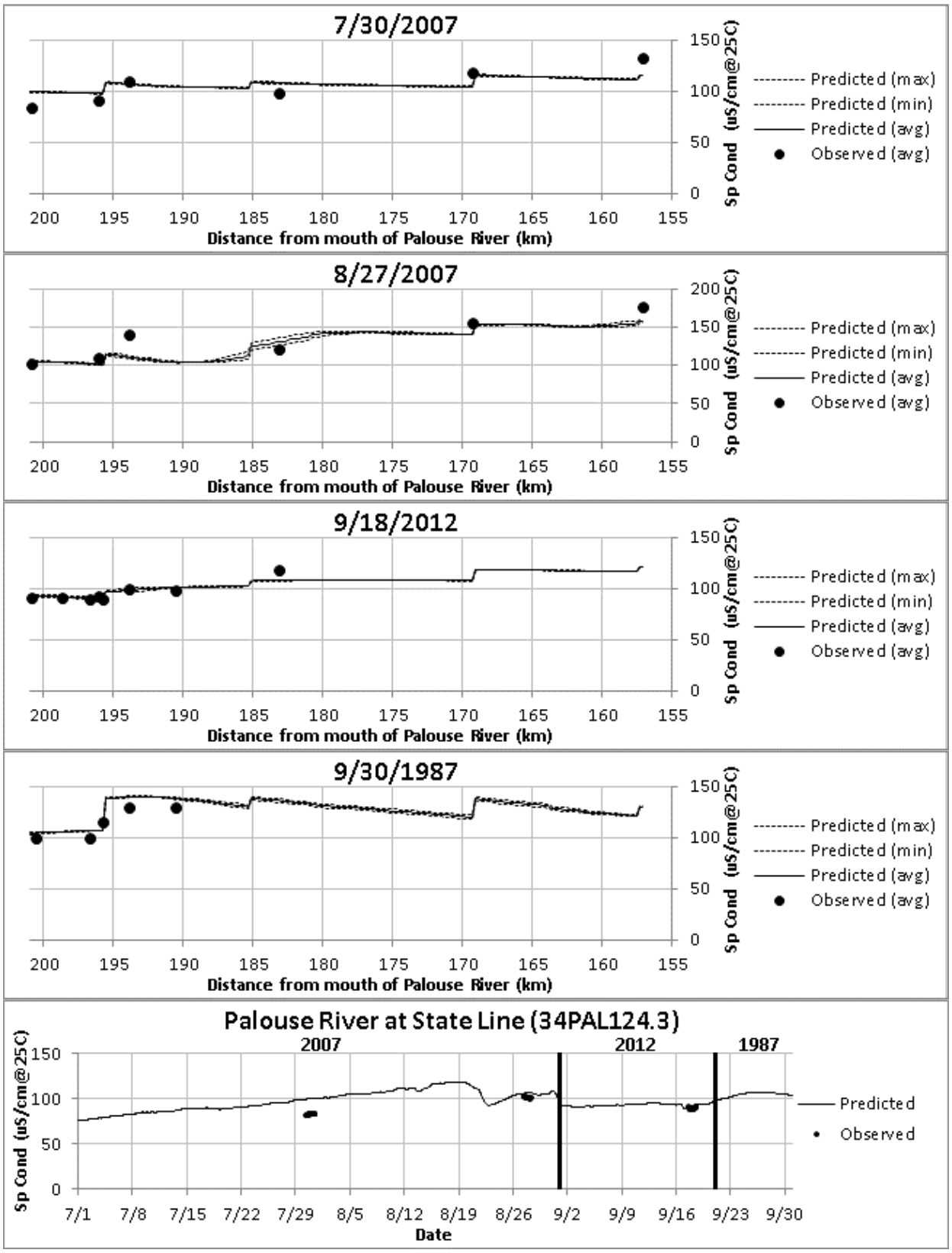
[18]Observed pH values at certain sites, particularly 34PAL120.3 (196km) in 2007, may reflect missed nutrient sources. These missed sources were not included in the model, so the predicted pH values do not match the observed values very well at those sites and times. Refer to Appendix D for a sensitivity analysis of potential sources.

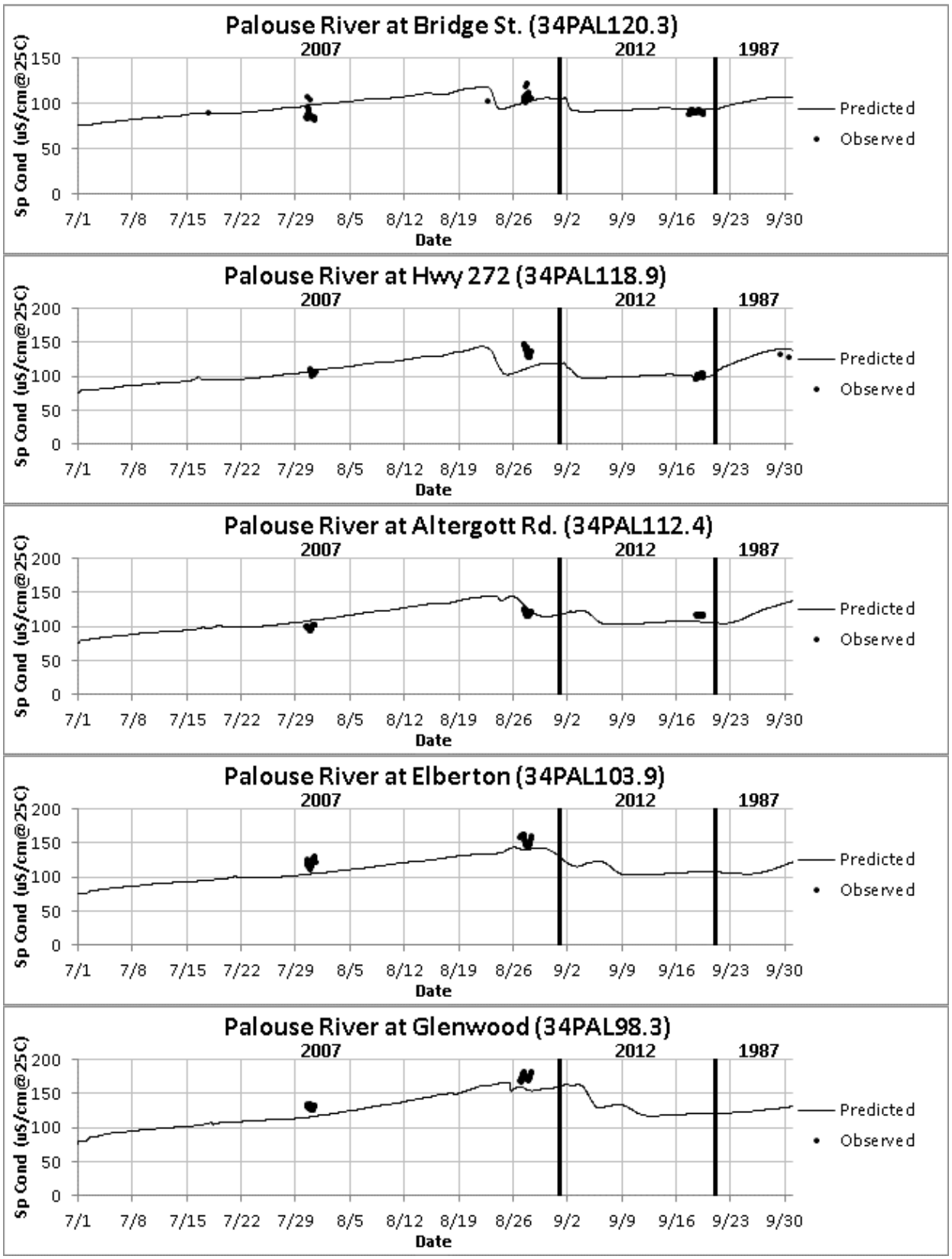

Palouse River at State Line (34PAL124.3)
Palouse River at Bridge St. (34PAL120.3)
Palouse River at Hwy 272 (34PAL118.9)
Palouse River at Altergott Rd. (34PAL112.4)
Palouse River at Elberton (34PAL103.9)
Palouse River at Glenwood (34PAL98.3)
2007
2012
1987
pH (S.U.)
11
10
9
8
7
6
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30
Date
Predicted
Observed


34PAL122.2
34PAL120.8
34PAL120.3
34PAL120.3
34PAL120.3
34PAL120.0
34PAL118.9
34PAL118.9
pH (S.U.)
Obs pH
Pred pH

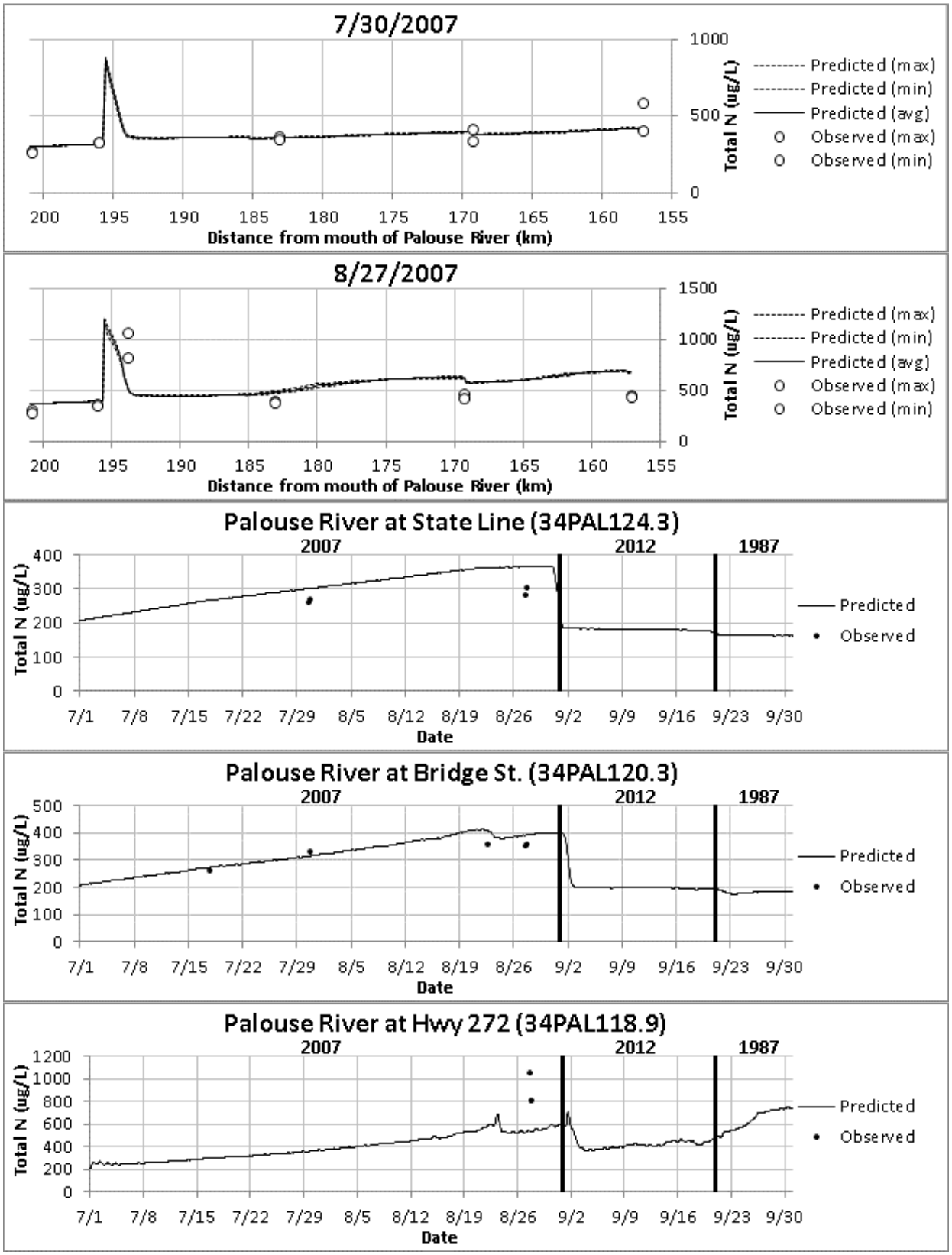

34PAL118.9
34PAL116.8
34PAL112.4
34PAL112.4
34PAL112.4
34PAL103.9
34PAL103.9
34PAL98.3
34PAL98.3
pH (S.U.)
Obs pH
Pred pH
9/18 6:00
9/18 12:00
9/18 18:00
9/19 0:00
9/19 6:00
9/19 12:00
7/30 6:00
7/30 12:00
7/30 18:00
7/31 0:00
7/31 6:00
7/31 12:00
8/26 12:00
8/26 18:00
8/27 0:00
8/27 6:00
8/27 12:00
8/27 18:00
8/28 0:00
8/28 6:00
8/28 12:00

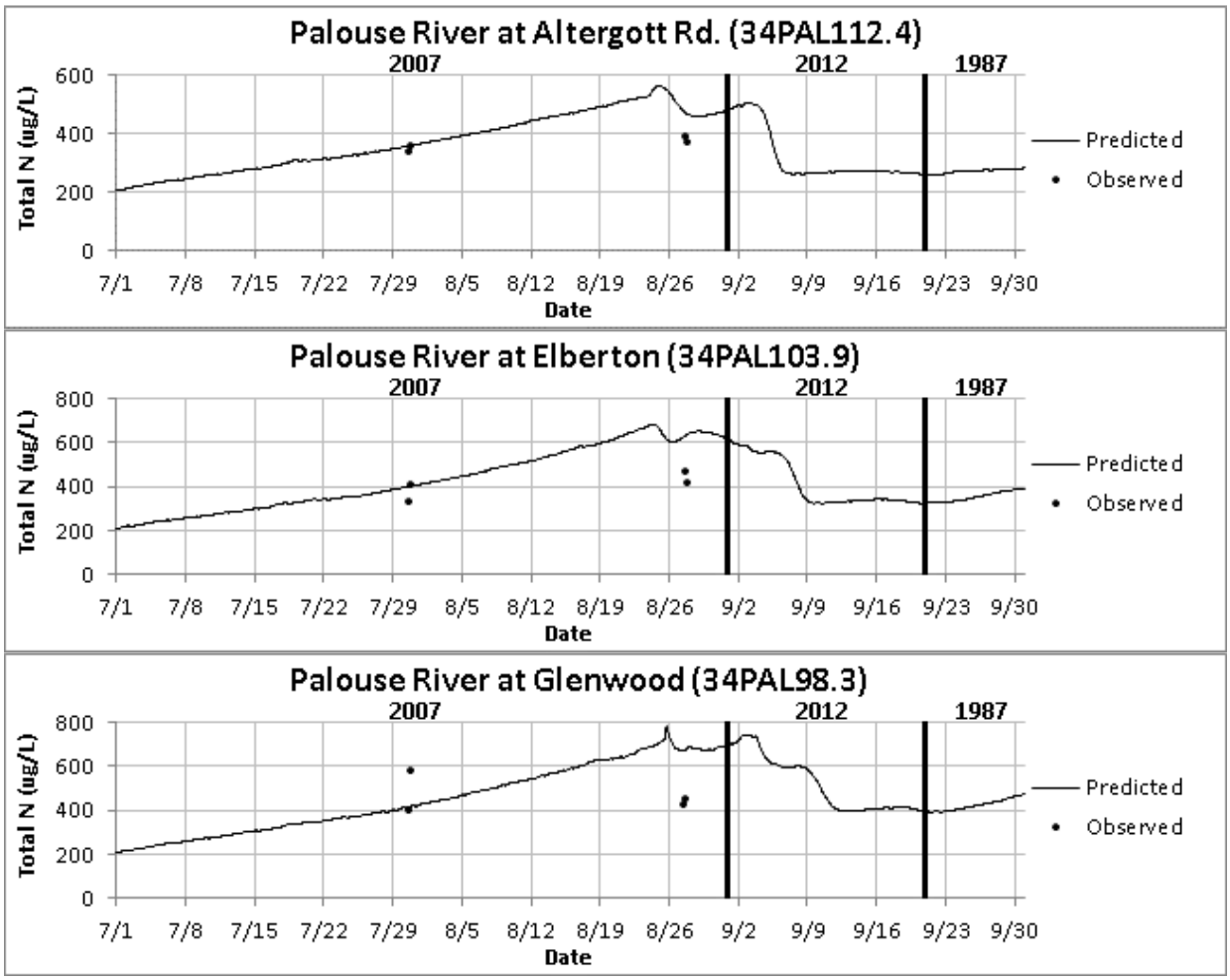
Specific Conductivity



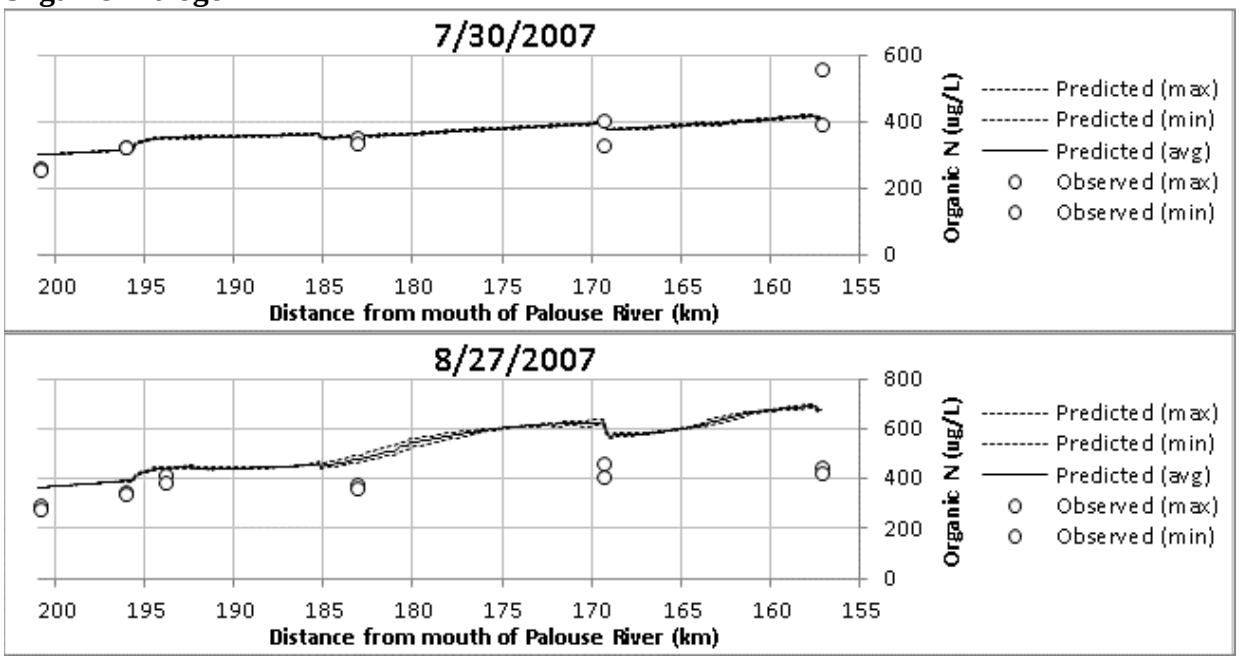

Palouse River at Bridge St. (34PAL120.3)
Palouse River at Hwy 272 (34PAL118.9)
Palouse River at Altergott Rd. (34PAL112.4)
Palouse River at Elberton (34PAL103.9)
Palouse River at Glenwood (34PAL98.3)
2007
2012
1987
Sp Cond (uS/cm@25C)
Date
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Predicted
Observed

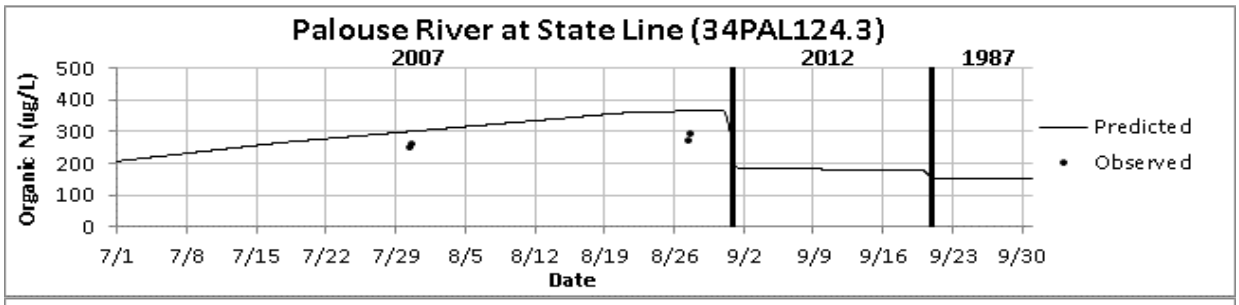
Total Nitrogen

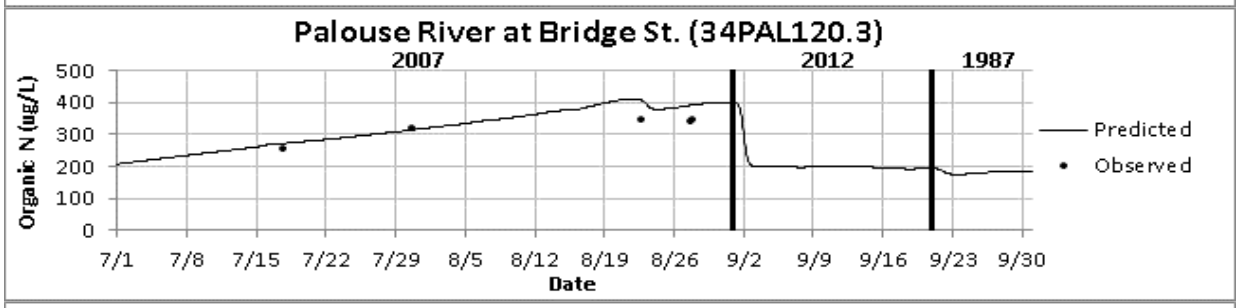


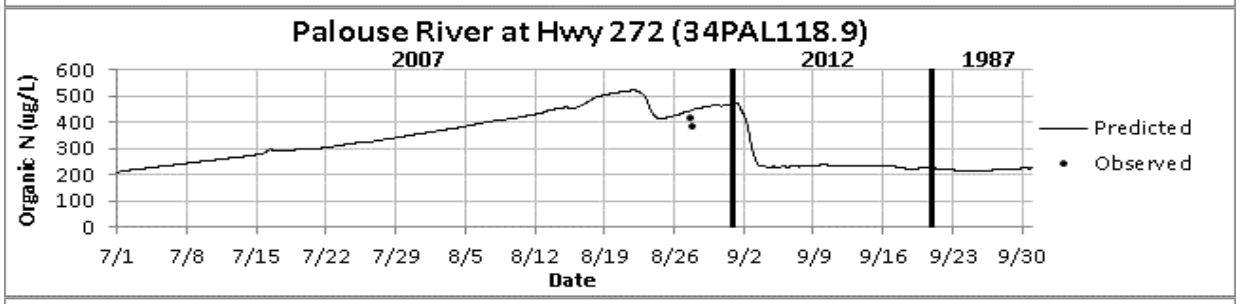


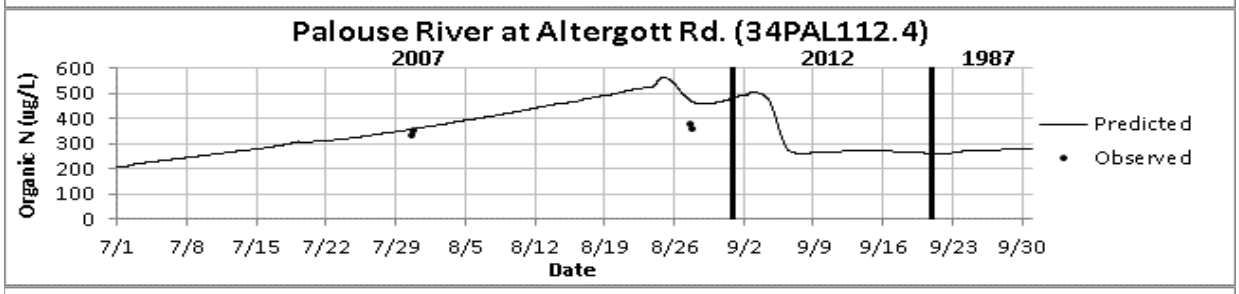
Organic Nitrogen

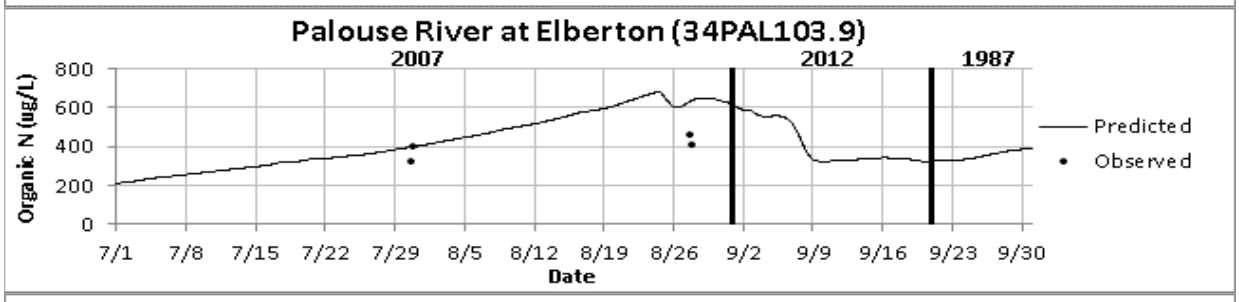


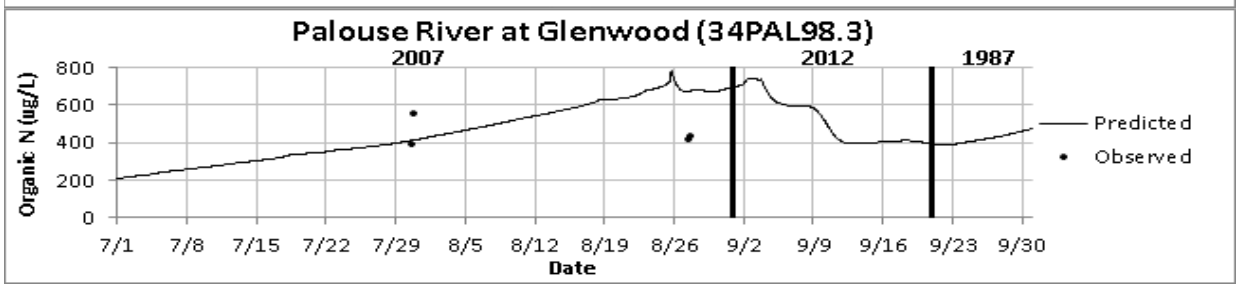

Palouse River at State Line (34PAL124.3)
2007
2012
1987
Organic N (ug/L)
500
400
300
200
100
0
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30
Date
Predicted
Observed


Palouse River at Bridge St. (34PAL120.3)
2007
2012
1987
Organic N (ug/L)
500
400
300
200
100
0
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30
Date
Predicted
Observed

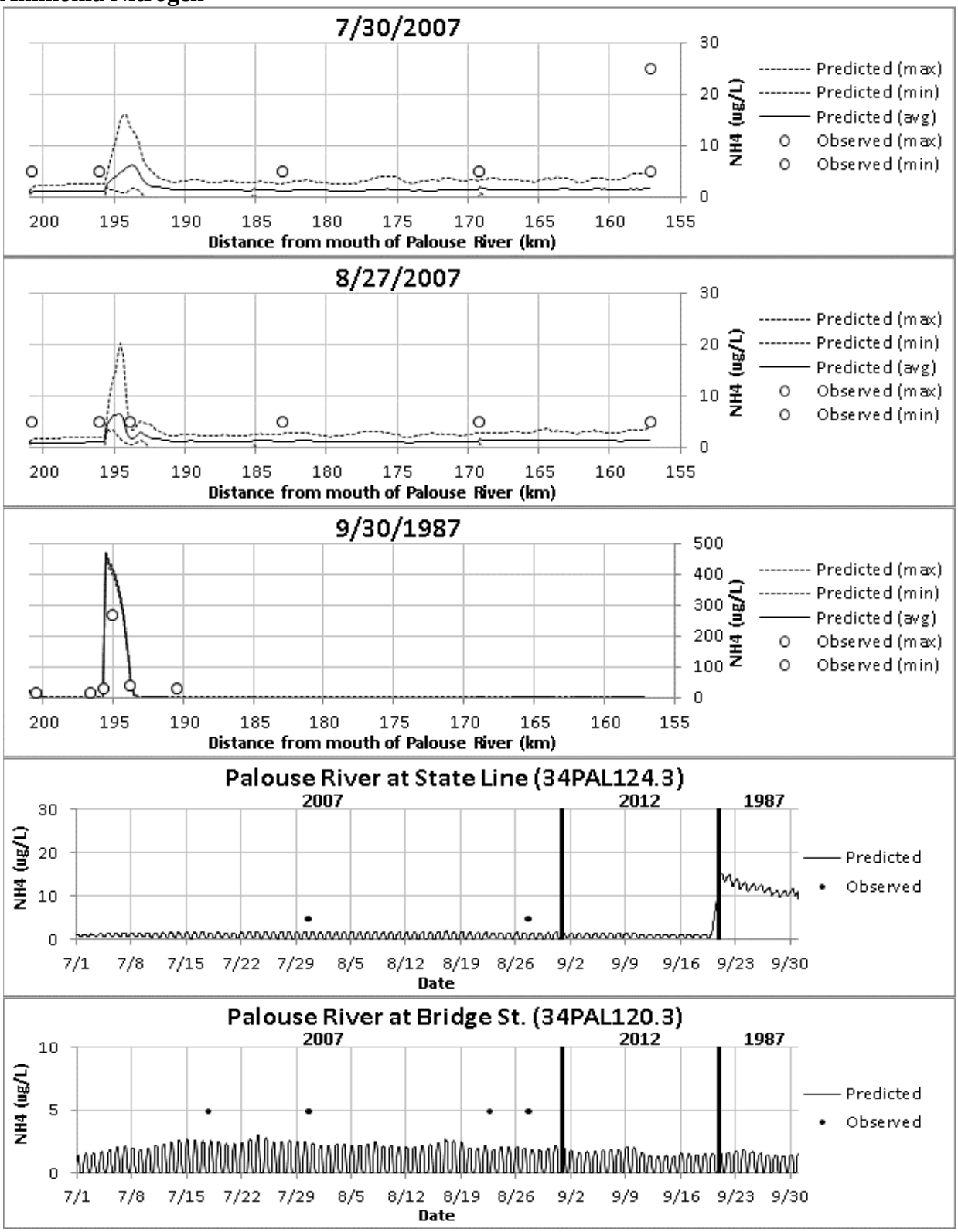

Palouse River at Hwy 272 (34PAL118.9)
2007
2012
1987
Organic N (ug/L)
600
500
400
300
200
100
0
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30
Date
Predicted
Observed


Palouse River at Altergott Rd. (34PAL112.4)
2007
2012
1987
Organic N (ug/L)
600
500
400
300
200
100
0
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30
Date
Predicted
Observed

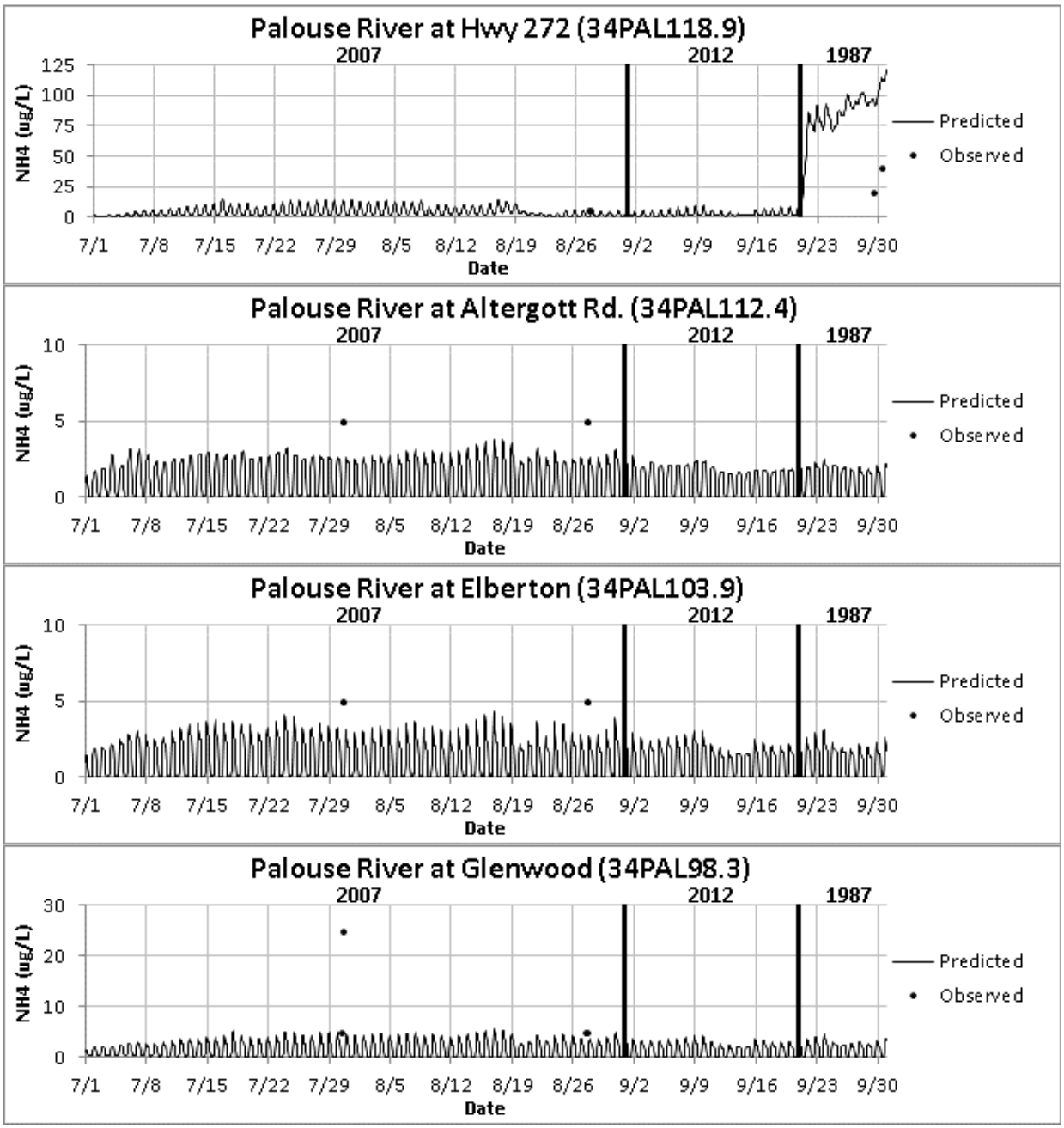

Palouse River at Elberton (34PAL103.9)
2007
2012
1987
Organic N (ug/L)
800
600
400
200
0
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30
Date
Predicted
Observed


Palouse River at Glenwood (34PAL98.3)
2007
2012
1987
Organic N (ug/L)
800
600
400
200
0
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30
Date
Predicted
Observed

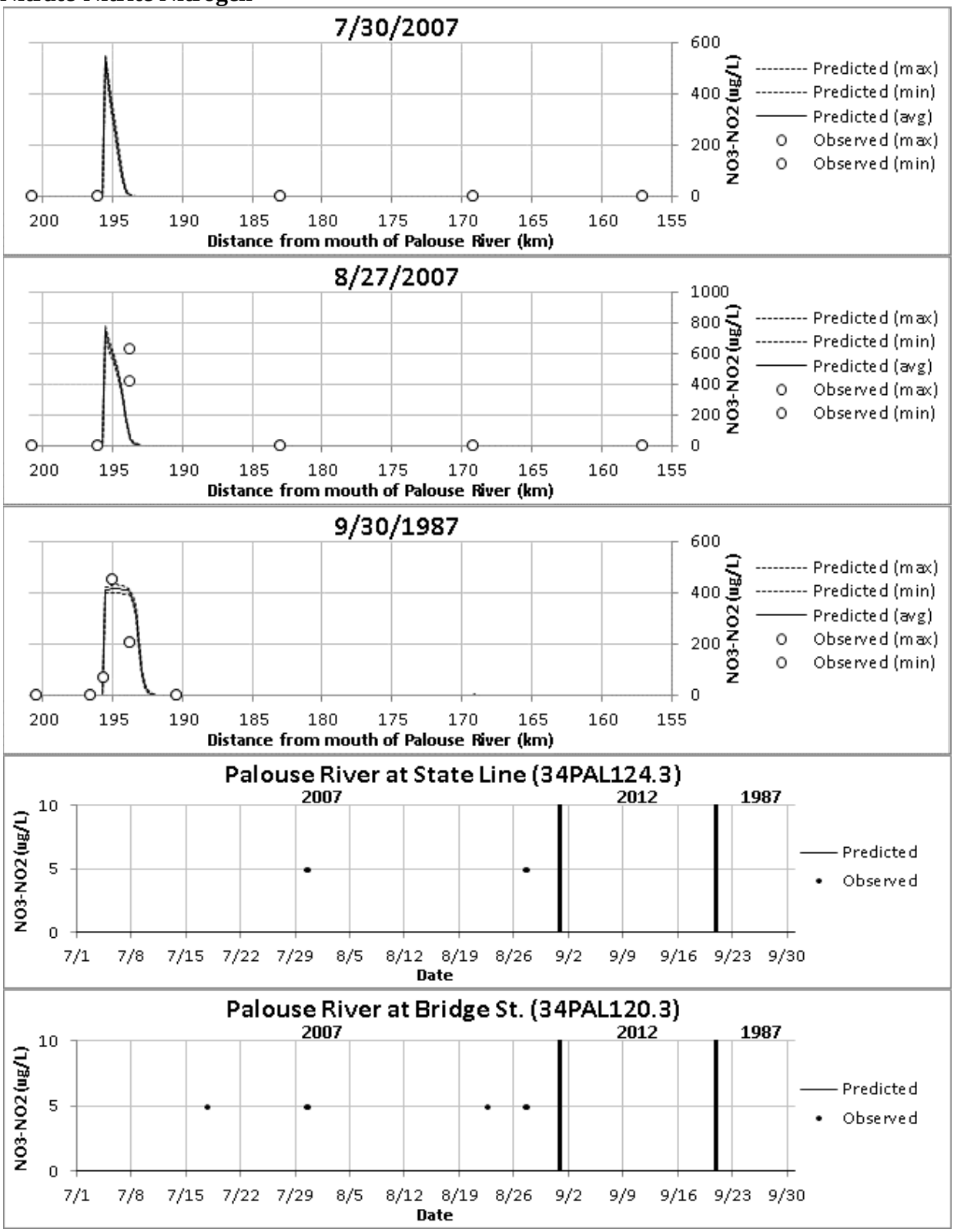
Ammonia Nitrogen[19]



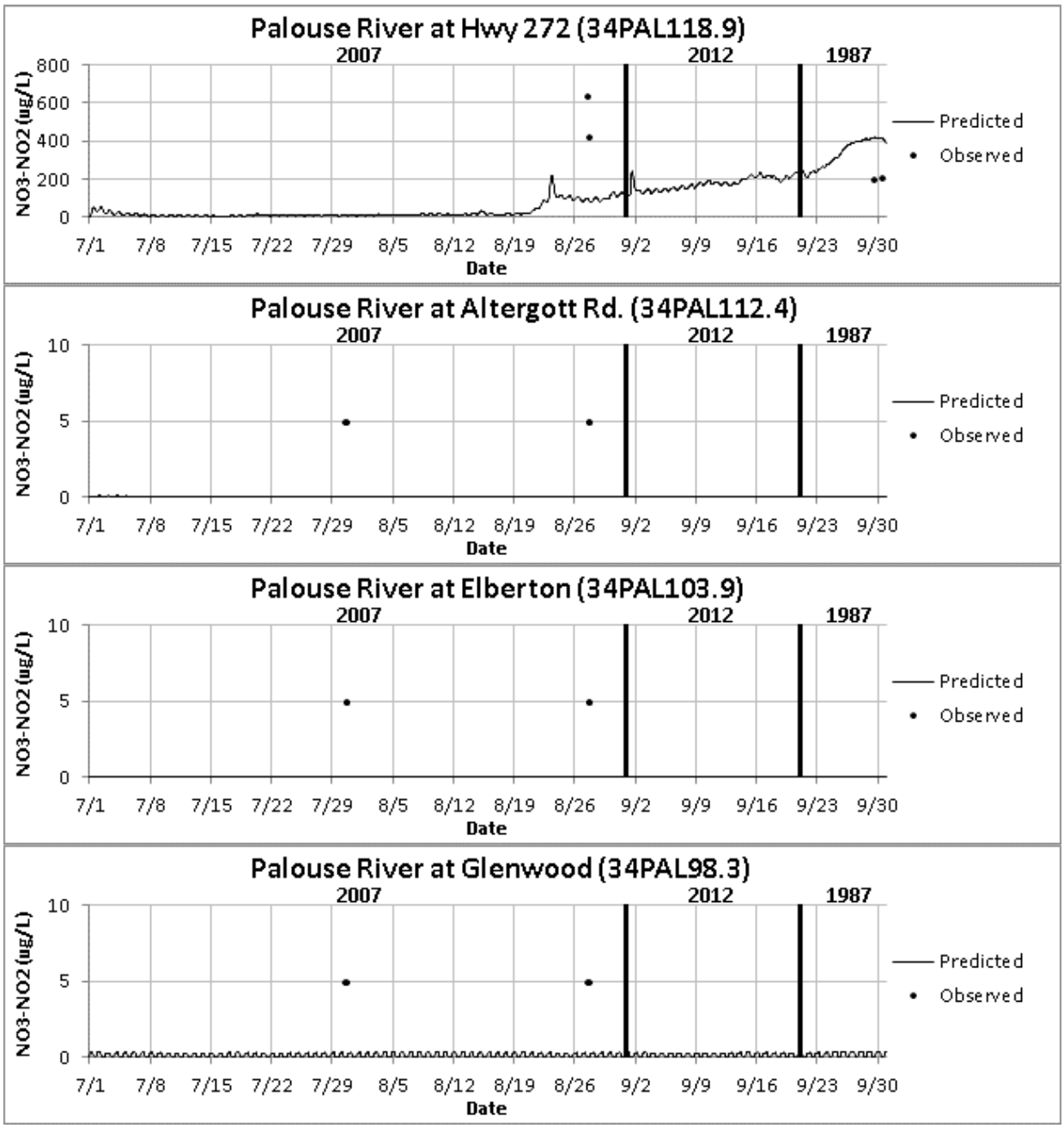
[19] The detection limit for Ammonia is 10 ug/L. On the plots, observed values of 5 ug/L represent non-detects. The actual value could be anything less than 10 ug/L.


Palouse River at Hwy 272 (34PAL118.9)
2007
2012
1987
NH4 (ug/L)
125
100
75
50
25
0
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30
Date
Predicted
Observed
Palouse River at Altergott Rd. (34PAL112.4)
2007
2012
1987
NH4 (ug/L)
10
5
0
Date
Predicted
Observed
Palouse River at Elberton (34PAL103.9)
2007
2012
1987
NH4 (ug/L)
10
5
0
Date
Predicted
Observed
Palouse River at Glenwood (34PAL98.3)
2007
2012
1987
NH4 (ug/L)
30
20
10
0
Date
Predicted
Observed

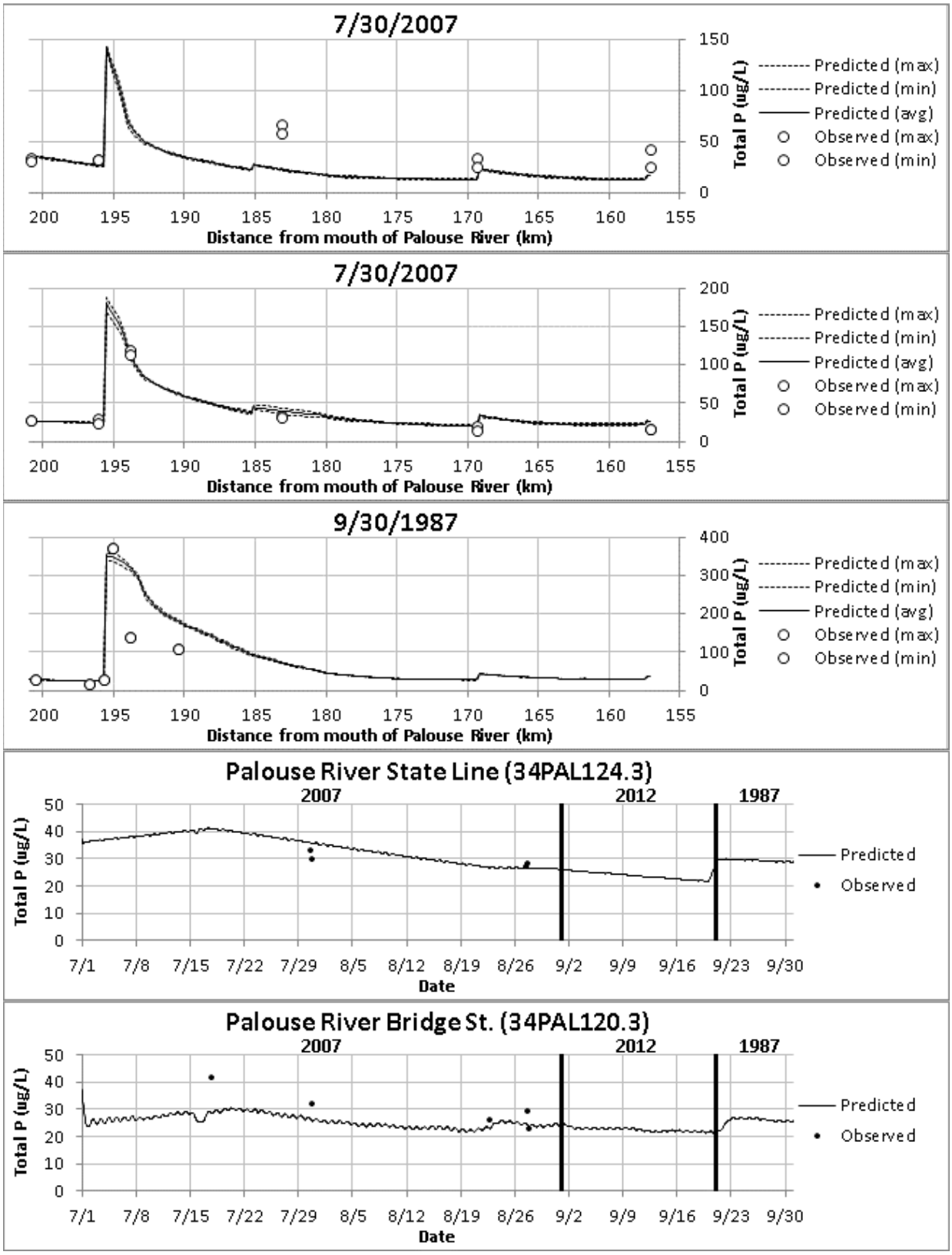
Nitrate-Nitrite Nitrogen[20]

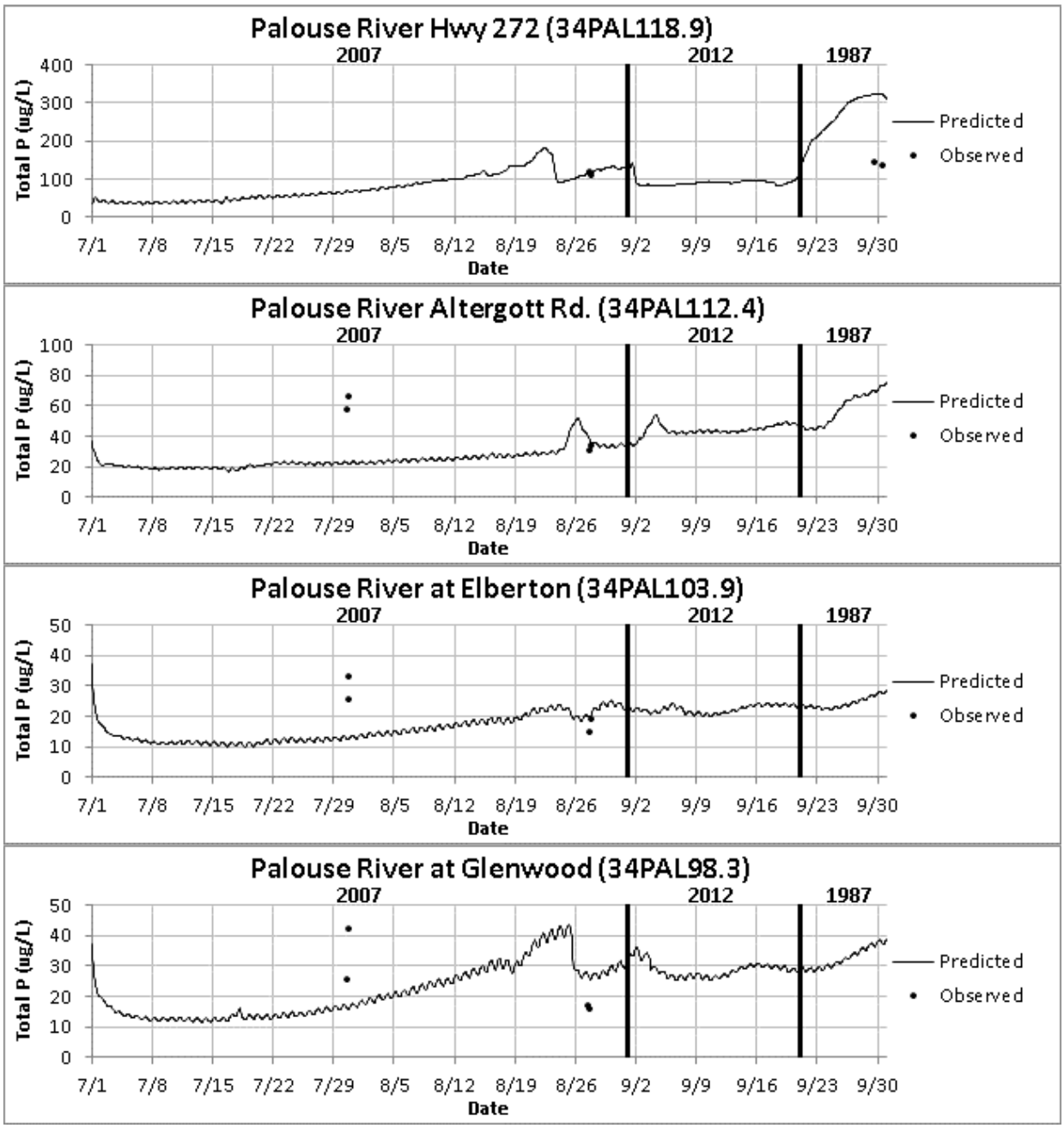


[20] The detection limit for Nitrate-Nitrite is 10 ug/L. On the plots, observed values of 5 ug/L represent non-detects. The actual value could be anything less than 10 ug/L.

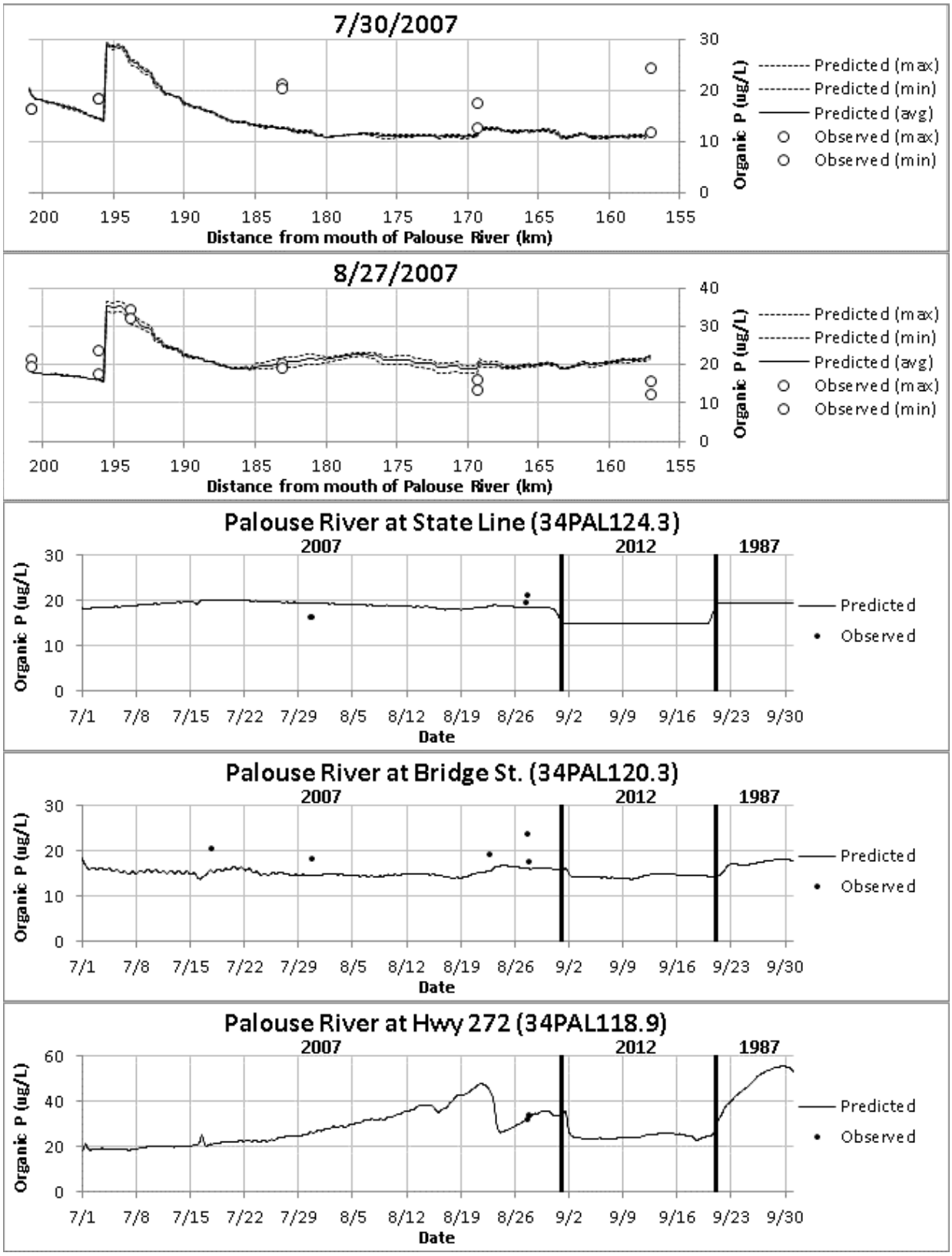

Palouse River at Hwy 272 (34PAL118.9)
2007
2012
1987
NO3-NO2 (ug/L)
800
600
400
200
0
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Date
Predicted
Observed
Palouse River at Altergott Rd. (34PAL112.4)
2007
2012
1987
NO3-NO2 (ug/L)
10
5
0
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Date
Predicted
Observed
Palouse River at Elberton (34PAL103.9)
2007
2012
1987
NO3-NO2 (ug/L)
10
5
0
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Date
Predicted
Observed
Palouse River at Glenwood (34PAL98.3)
2007
2012
1987
NO3-NO2 (ug/L)
10
5
0
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Date
Predicted
Observed

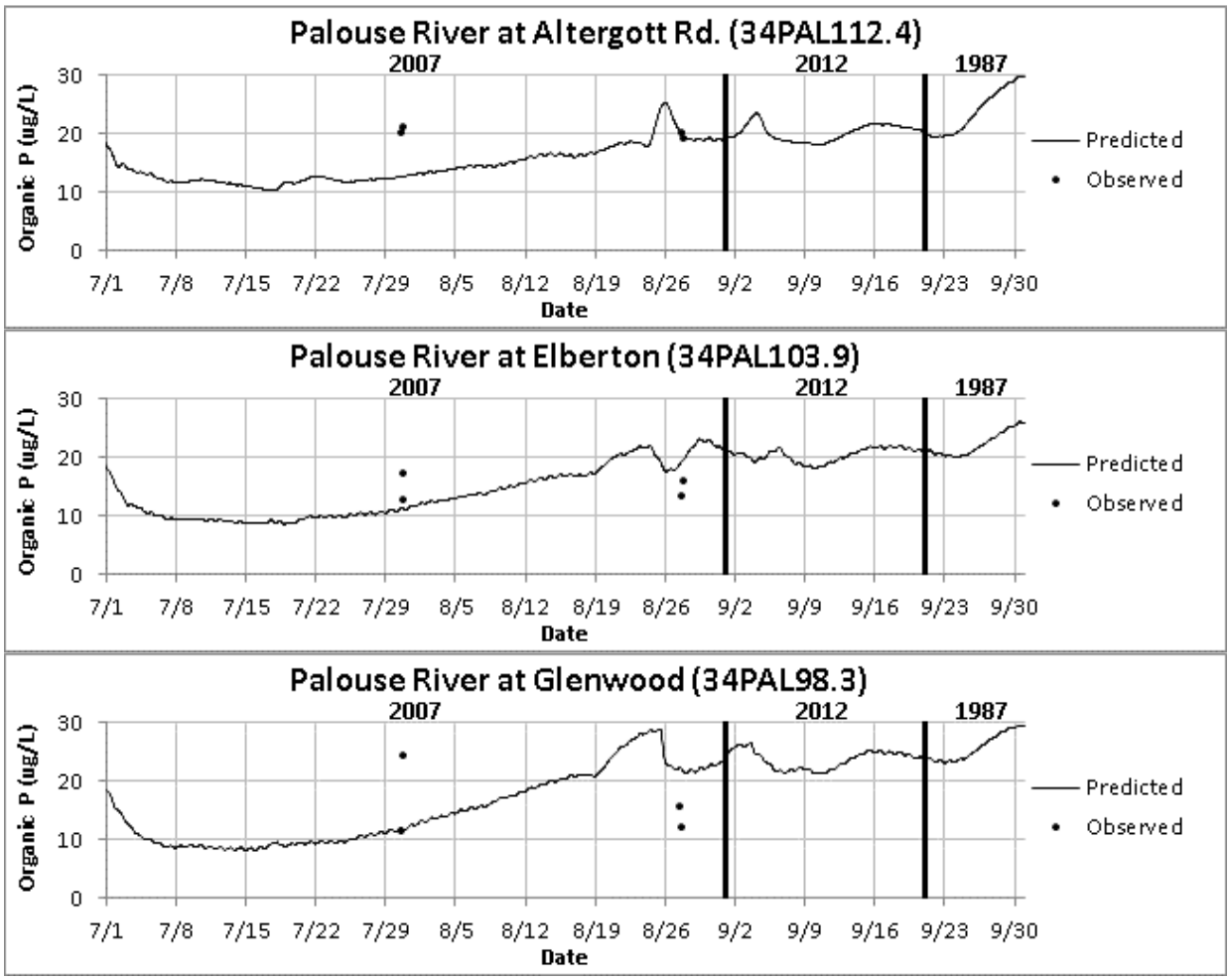
Total Phosphorus



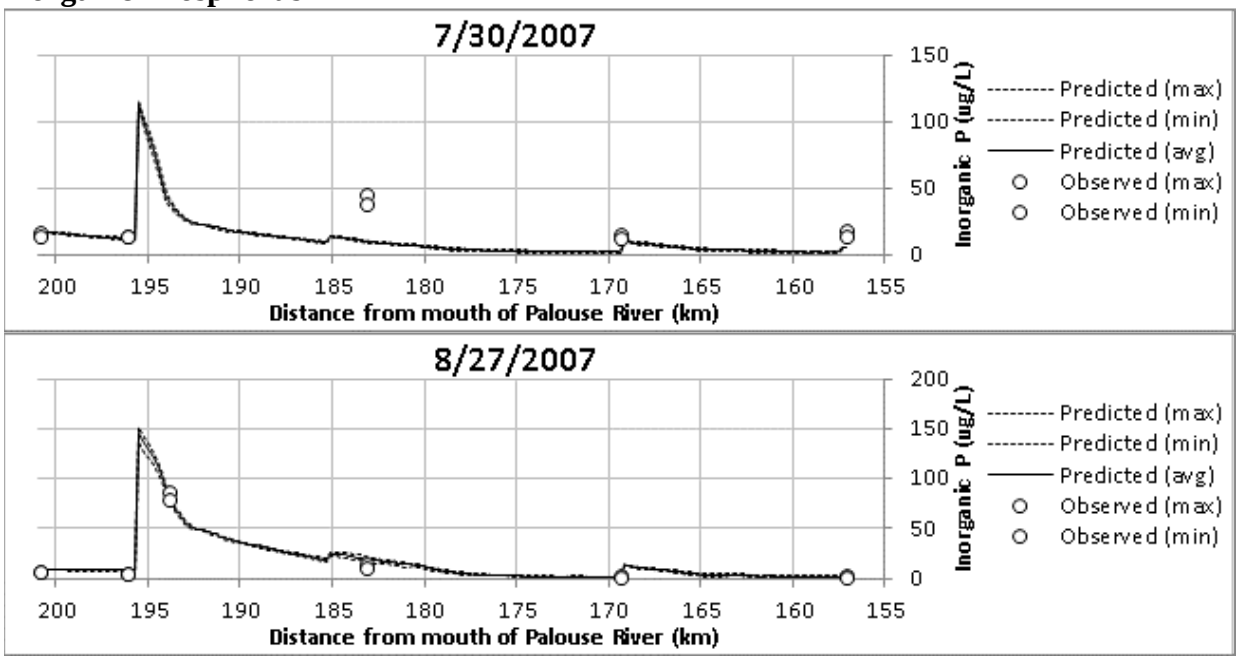

Palouse River Hwy 272 (34PAL118.9)
2007
2012
1987
Total P (ug/L)
Date
Predicted
Observed
Palouse River Altergott Rd. (34PAL112.4)
2007
2012
1987
Total P (ug/L)
Date
Predicted
Observed
Palouse River at Elberton (34PAL103.9)
2007
2012
1987
Total P (ug/L)
Date
Predicted
Observed
Palouse River at Glenwood (34PAL98.3)
2007
2012
1987
Total P (ug/L)
Date
Predicted
Observed

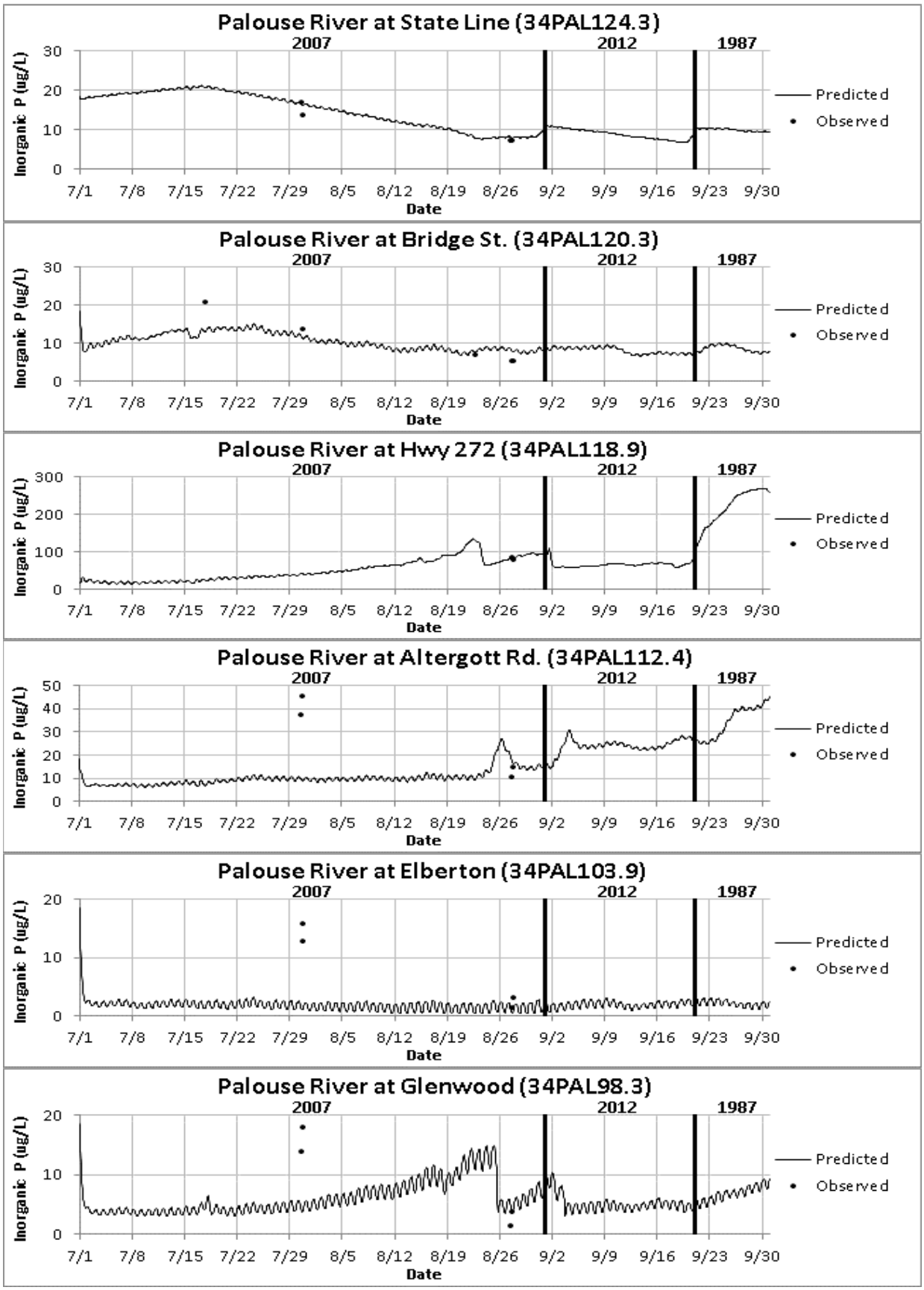
Organic Phosphorus



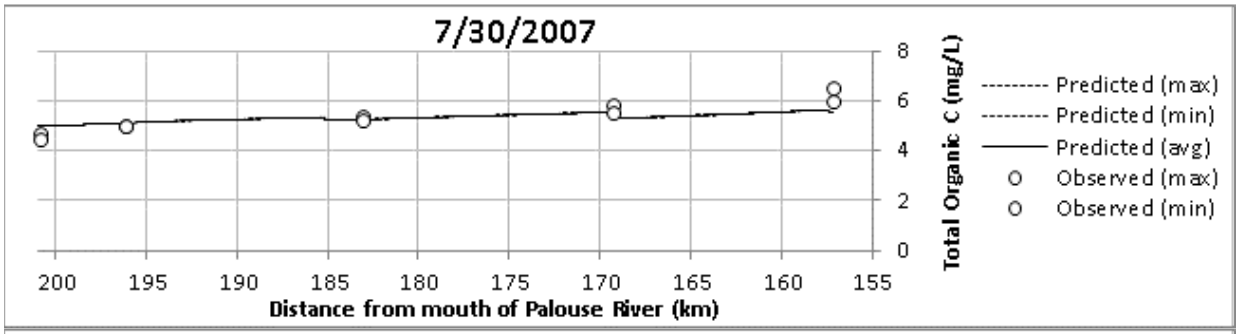


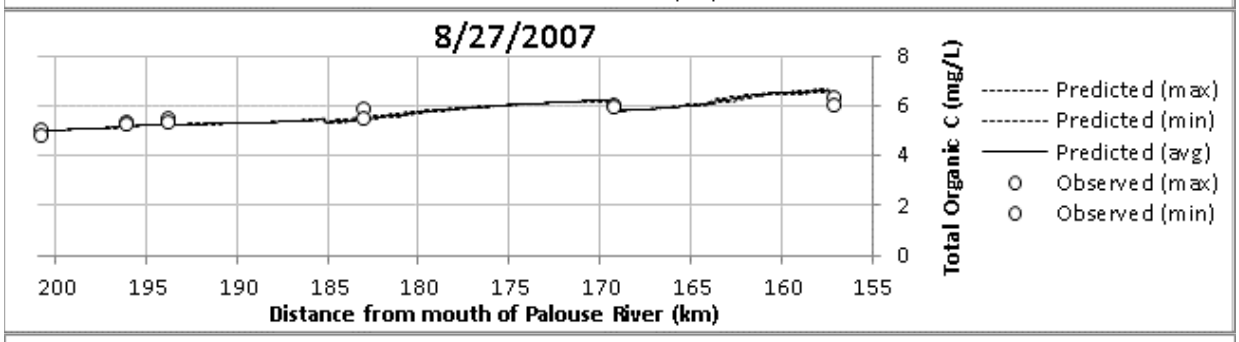
Inorganic Phosphorus

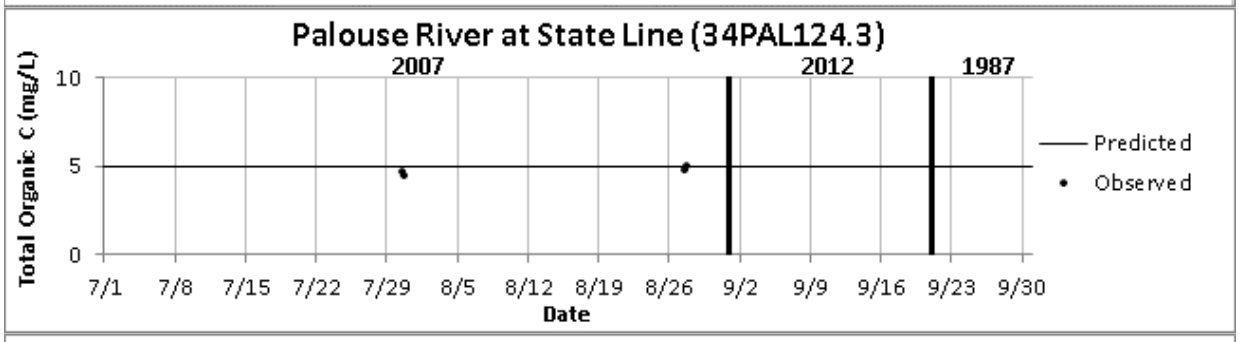


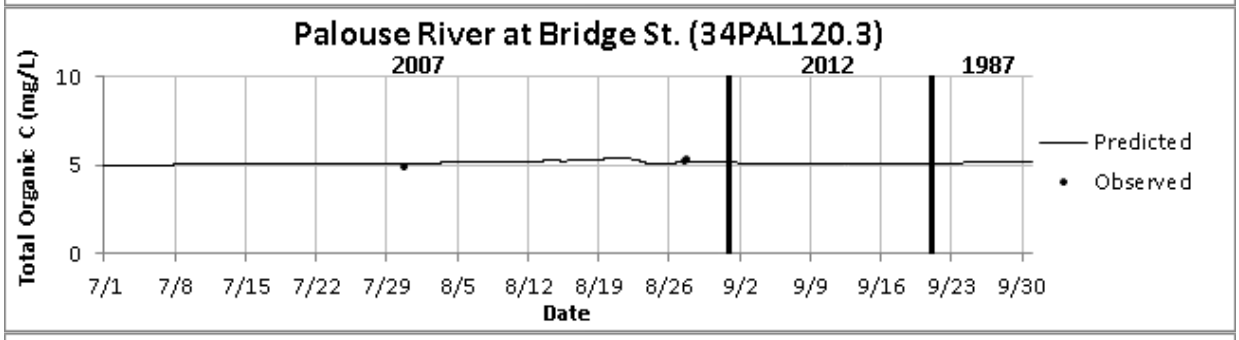

Palouse River at State Line (34PAL124.3)
Palouse River at Bridge St. (34PAL120.3)
Palouse River at Hwy 272 (34PAL118.9)
Palouse River at Altergott Rd. (34PAL112.4)
Palouse River at Elberton (34PAL103.9)
Palouse River at Glenwood (34PAL98.3)
2007
2012
1987
Inorganic P (ug/L)
Date
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Predicted
Observed

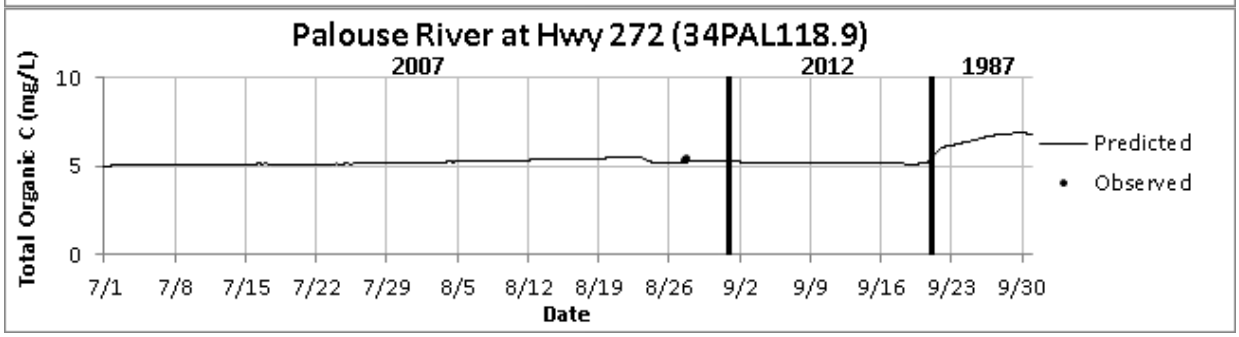
Total Organic Carbon

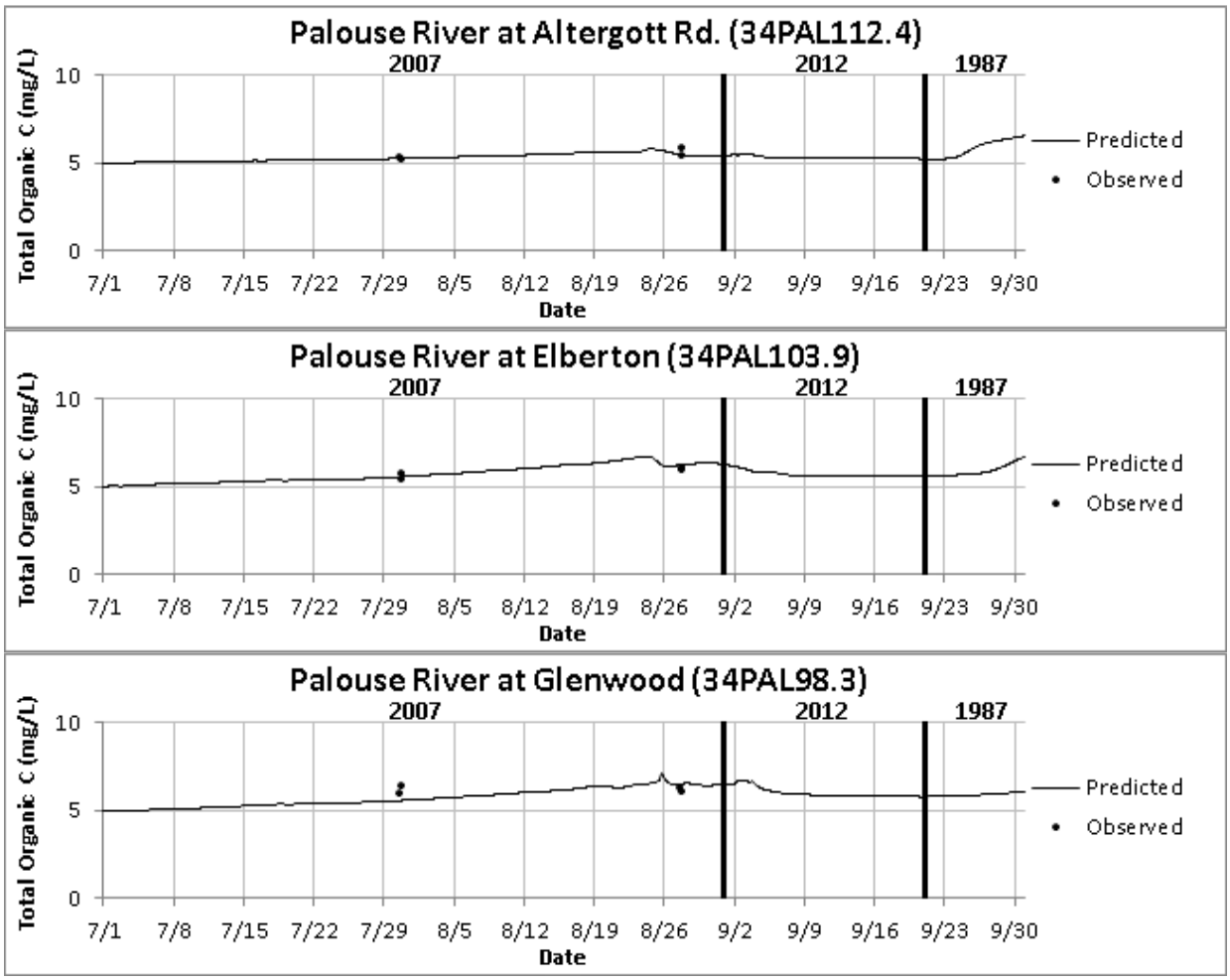




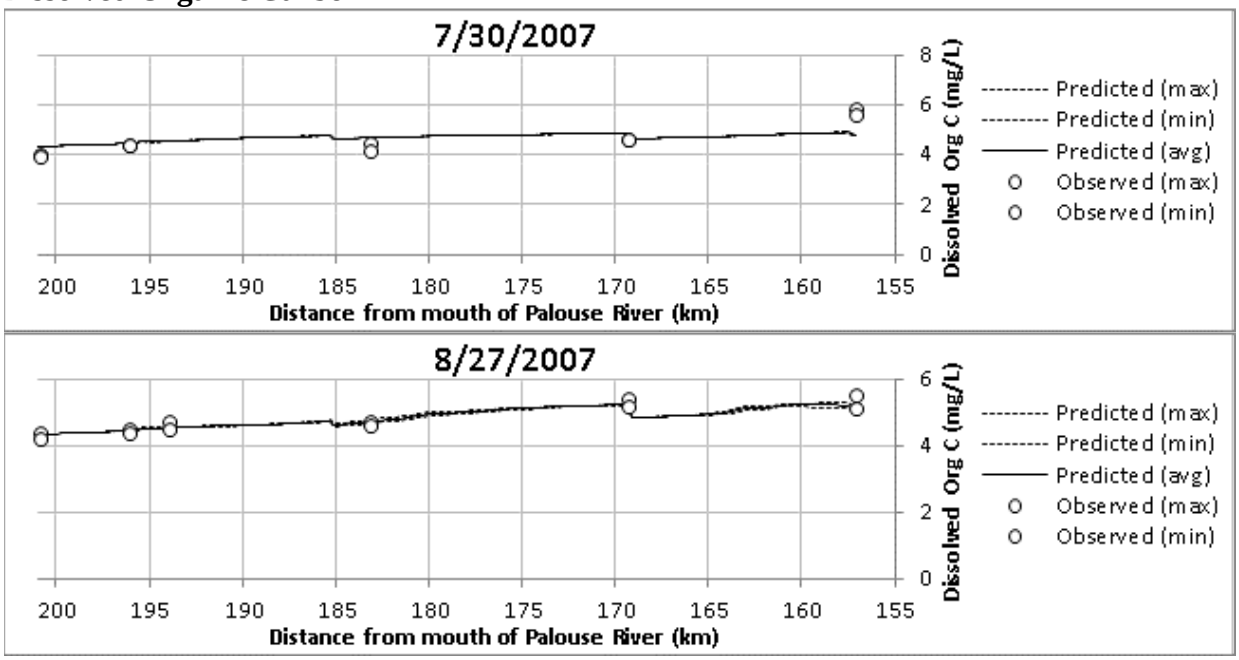


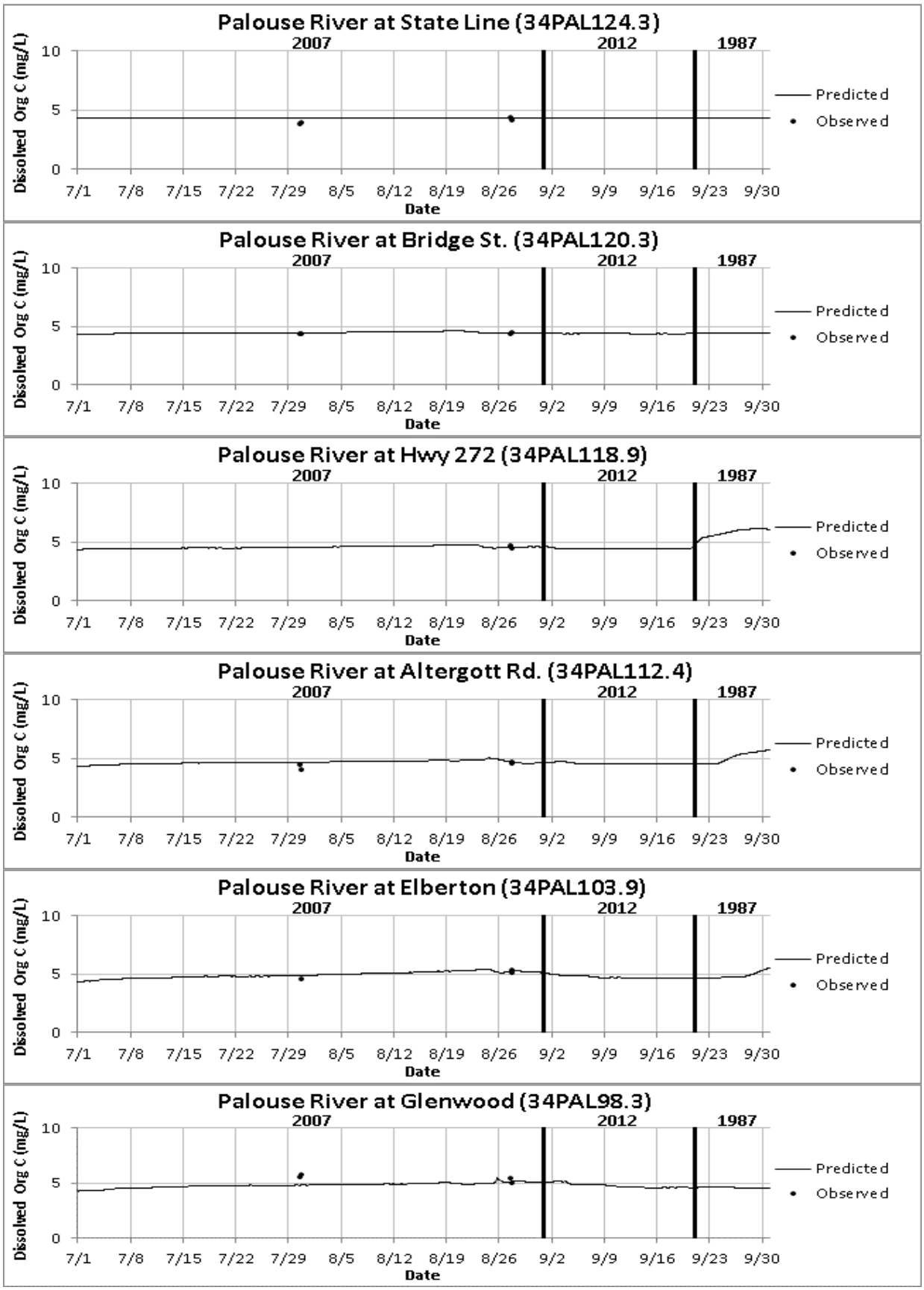




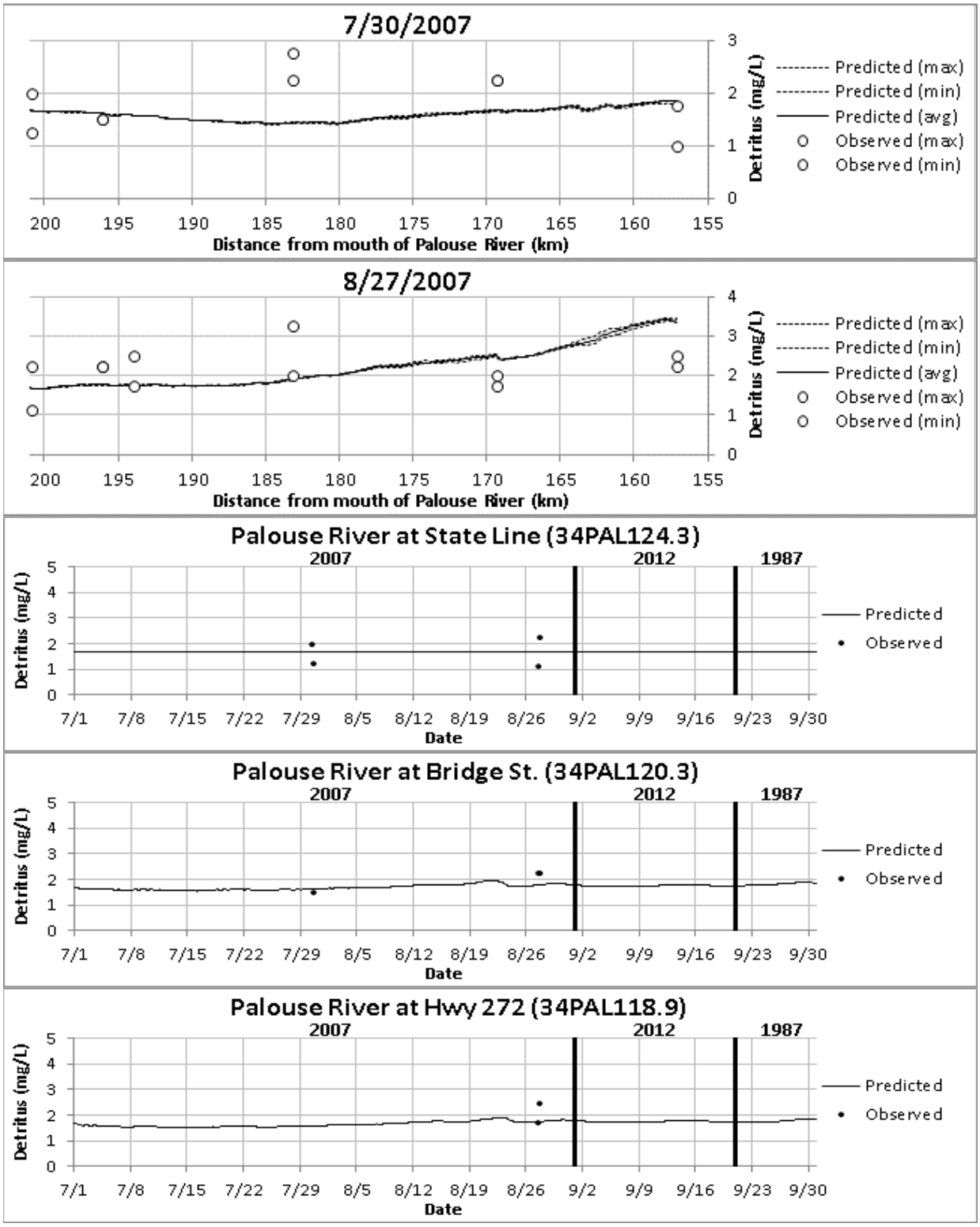


Dissolved Organic Carbon

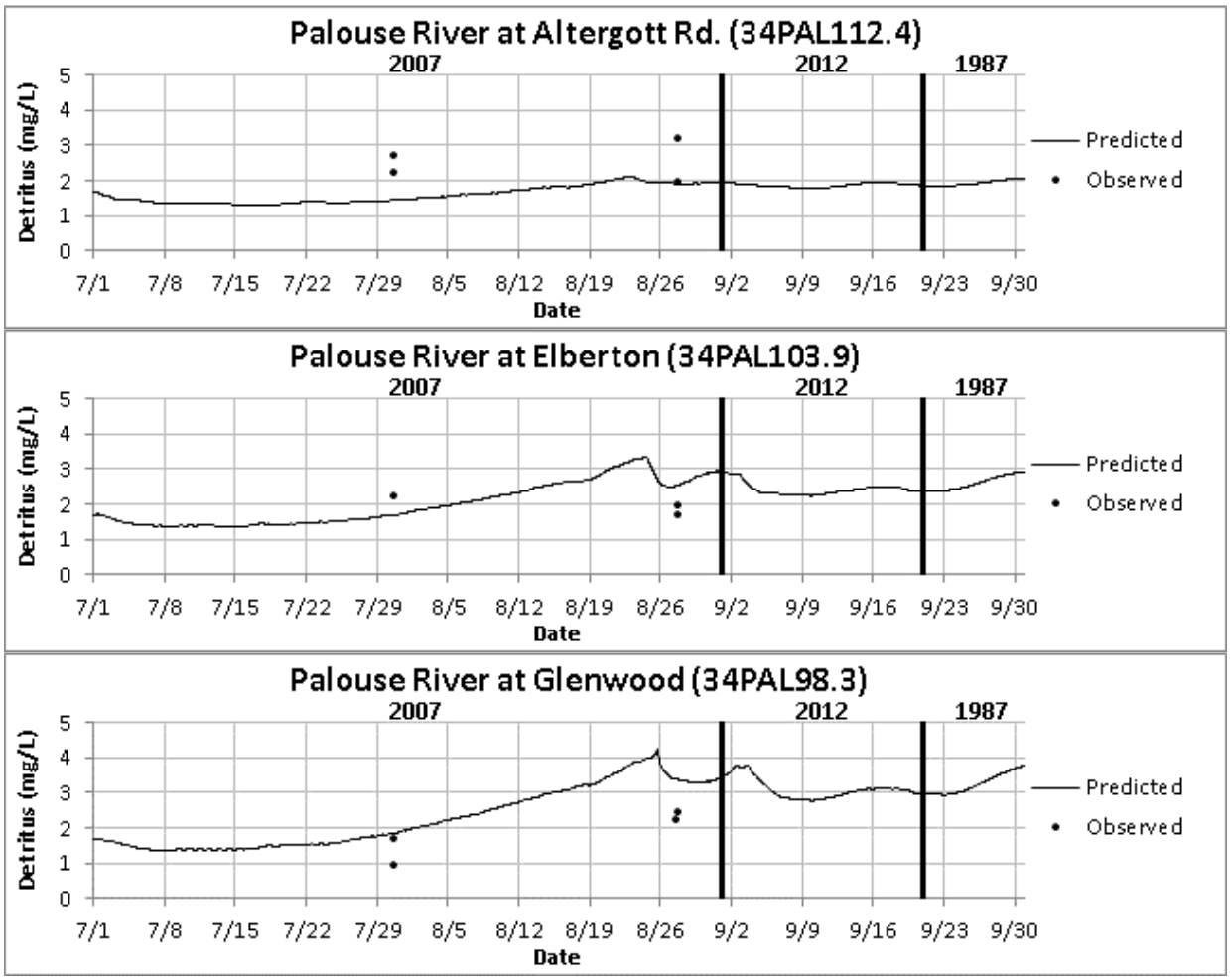



Palouse River at State Line (34PAL124.3)
Palouse River at Bridge St. (34PAL120.3)
Palouse River at Hwy 272 (34PAL118.9)
Palouse River at Altergott Rd. (34PAL112.4)
Palouse River at Elberton (34PAL103.9)
Palouse River at Glenwood (34PAL98.3)
2007
2012
1987
Dissolved Org C (mg/L)
10
5
0
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30
Date
Predicted
Observed

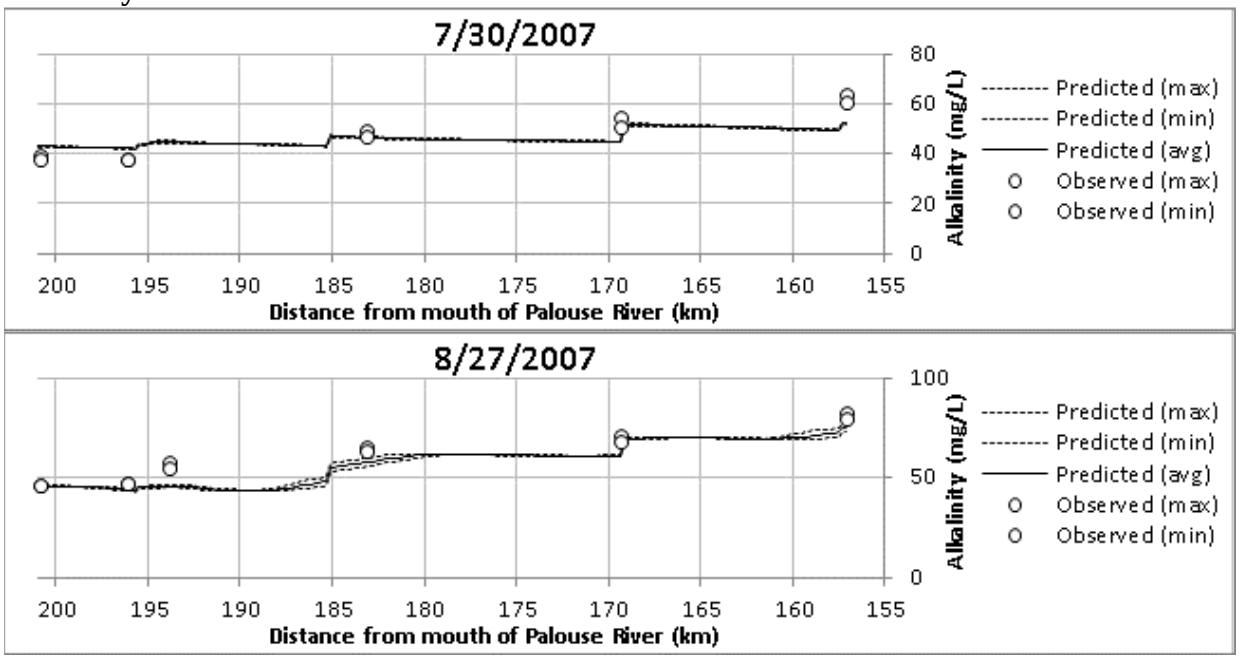
Detritus[21]

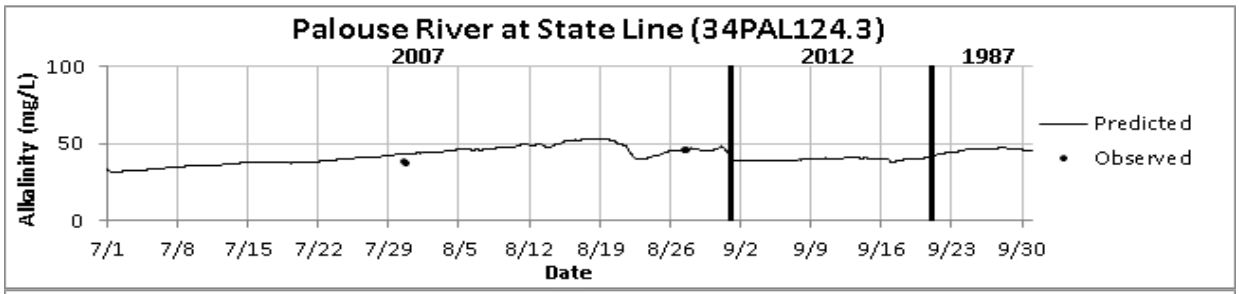


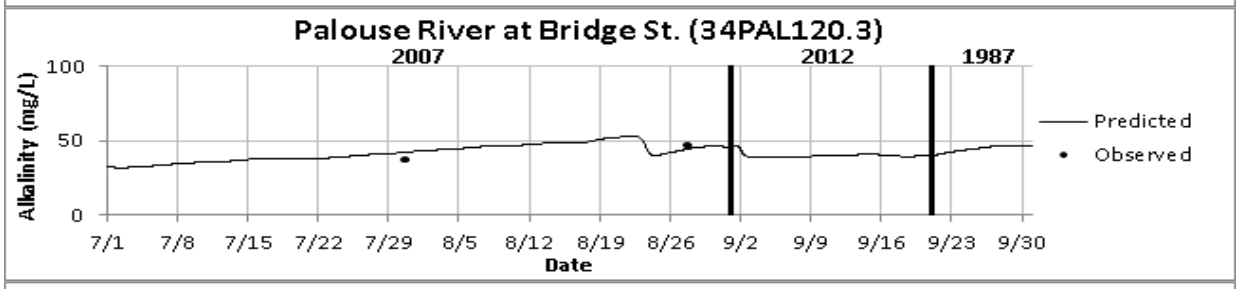
[21] "Observed" data values for detritus are calculated from laboratory data as (TOC-DOC)*2.5, where TOC-DOC represents particulate organic carbon (POC) and 2.5 is the assumed stoichiometric ratio of dry weight to carbon.

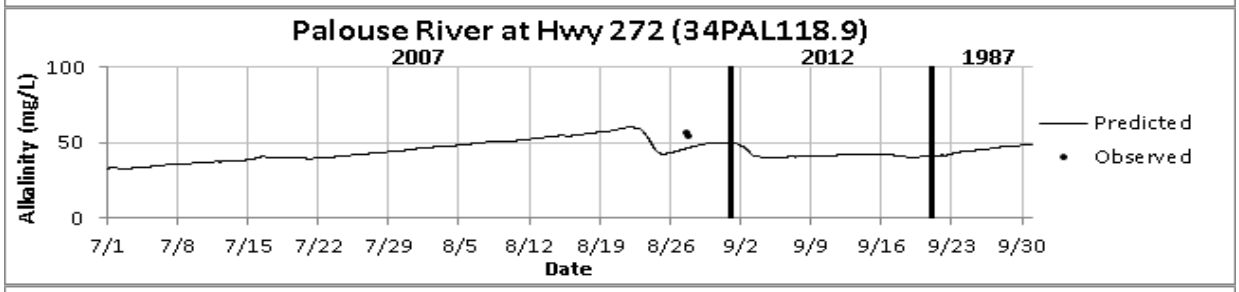

Palouse River at Altergott Rd. (34PAL112.4)
2007
2012
1987
Detritus (mg/L)
Date
Predicted
Observed
Palouse River at Elberton (34PAL103.9)
2007
2012
1987
Detritus (mg/L)
Date
Predicted
Observed
Palouse River at Glenwood (34PAL98.3)
2007
2012
1987
Detritus (mg/L)
Date
Predicted
Observed

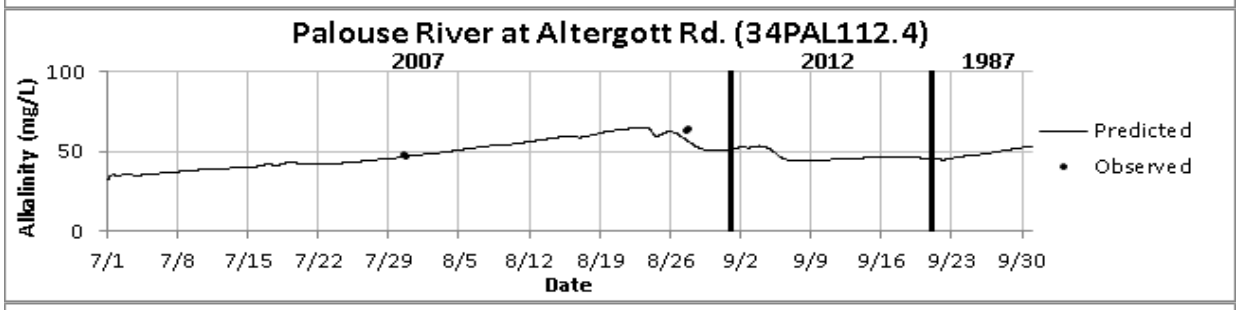
Alkalinity

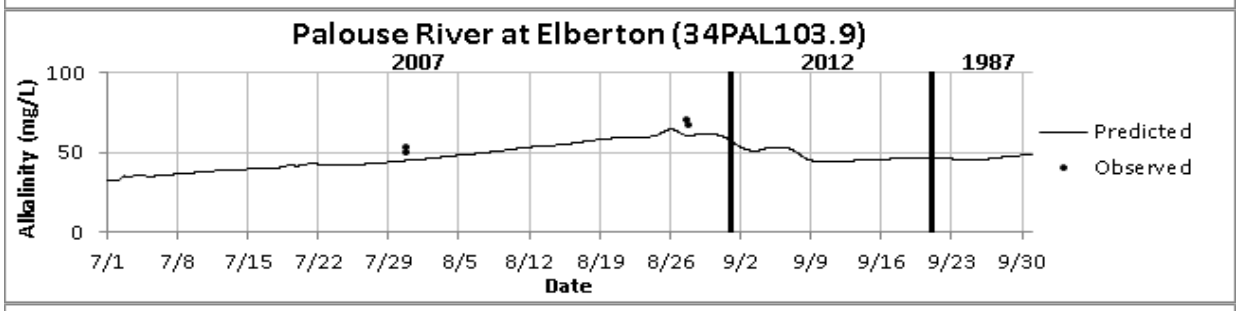

7/30/2007
Alkalinity (mg/L)
Distance from mouth of Palouse River (km)
Predicted (max)
Predicted (min)
Predicted (avg)
Observed (max)
Observed (min)
8/27/2007
Alkalinity (mg/L)
Distance from mouth of Palouse River (km)
Predicted (max)
Predicted (min)
Predicted (avg)
Observed (max)
Observed (min)

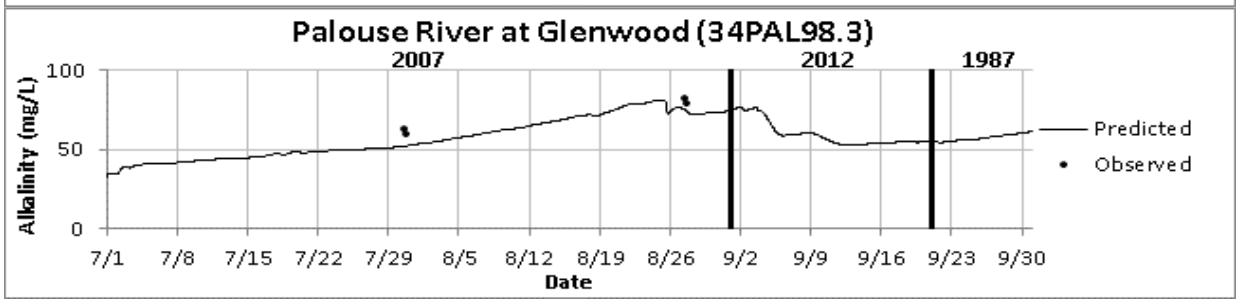

Palouse River at State Line (34PAL124.3)
2007
2012
1987
Alkalinity (mg/L)
100
50
0
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Date
Predicted
Observed


Palouse River at Bridge St. (34PAL120.3)
2007
2012
1987
Alkalinity (mg/L)
100
50
0
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Date
Predicted
Observed

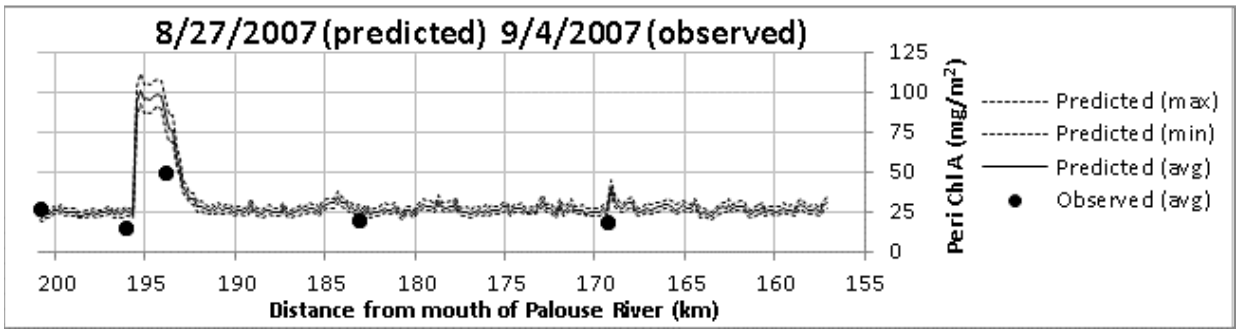

Palouse River at Hwy 272 (34PAL118.9)
2007
2012
1987
Alkalinity (mg/L)
100
50
0
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Date
Predicted
Observed


Palouse River at Altergott Rd. (34PAL112.4)
2007
2012
1987
Alkalinity (mg/L)
100
50
0
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Date
Predicted
Observed

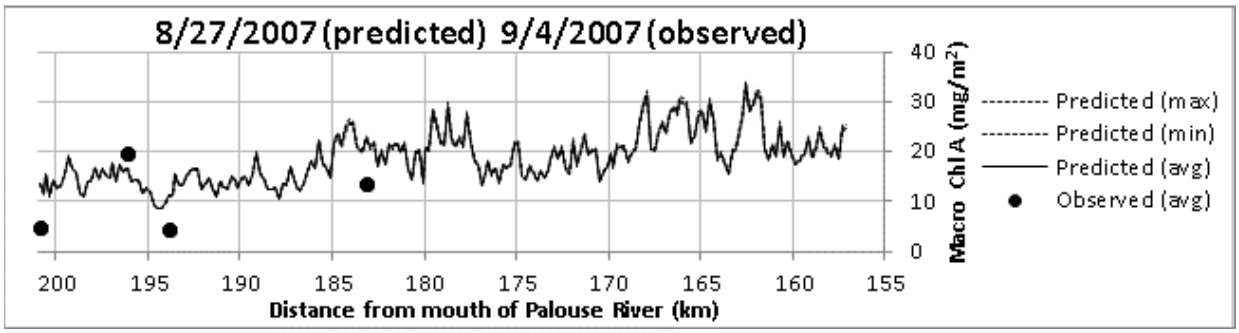

Palouse River at Elberton (34PAL103.9)
2007
2012
1987
Alkalinity (mg/L)
100
50
0
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Date
Predicted
Observed


Palouse River at Glenwood (34PAL98.3)
2007
2012
1987
Alkalinity (mg/L)
100
50
0
7/1 7/8 7/15 7/22 7/29 8/5 8/12 8/19 8/26 9/2 9/9 9/16 9/23 9/30
Date
Predicted
Observed

Periphyton biomass as Chlorophyll *a*



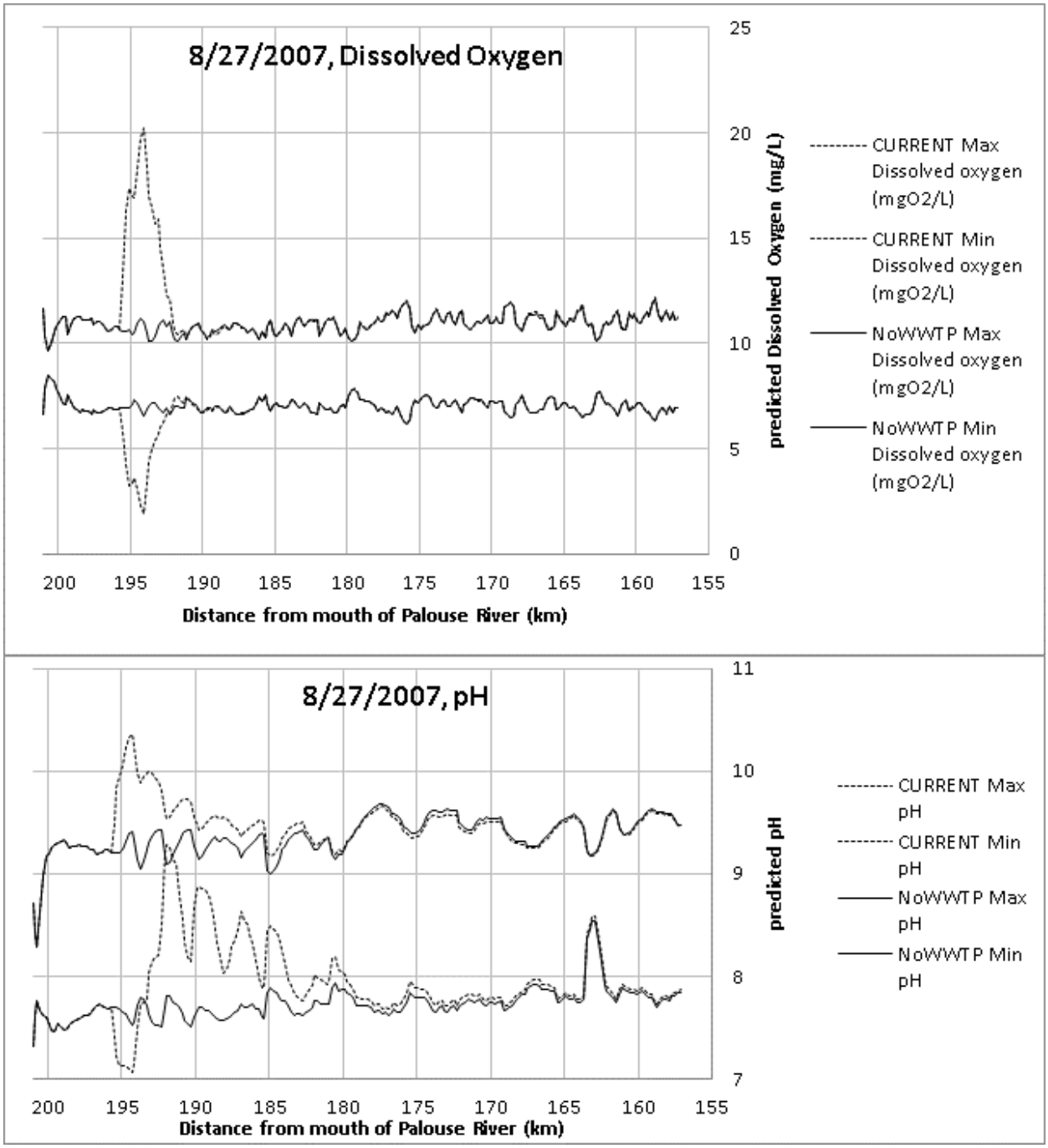
Macrophyte biomass as Chlorophyll *a*[22]



[22] There is an additional off-the-chart data point of 308 mg/m^2 at 159km (34PAL103.9). This is probably not representative of typical conditions.

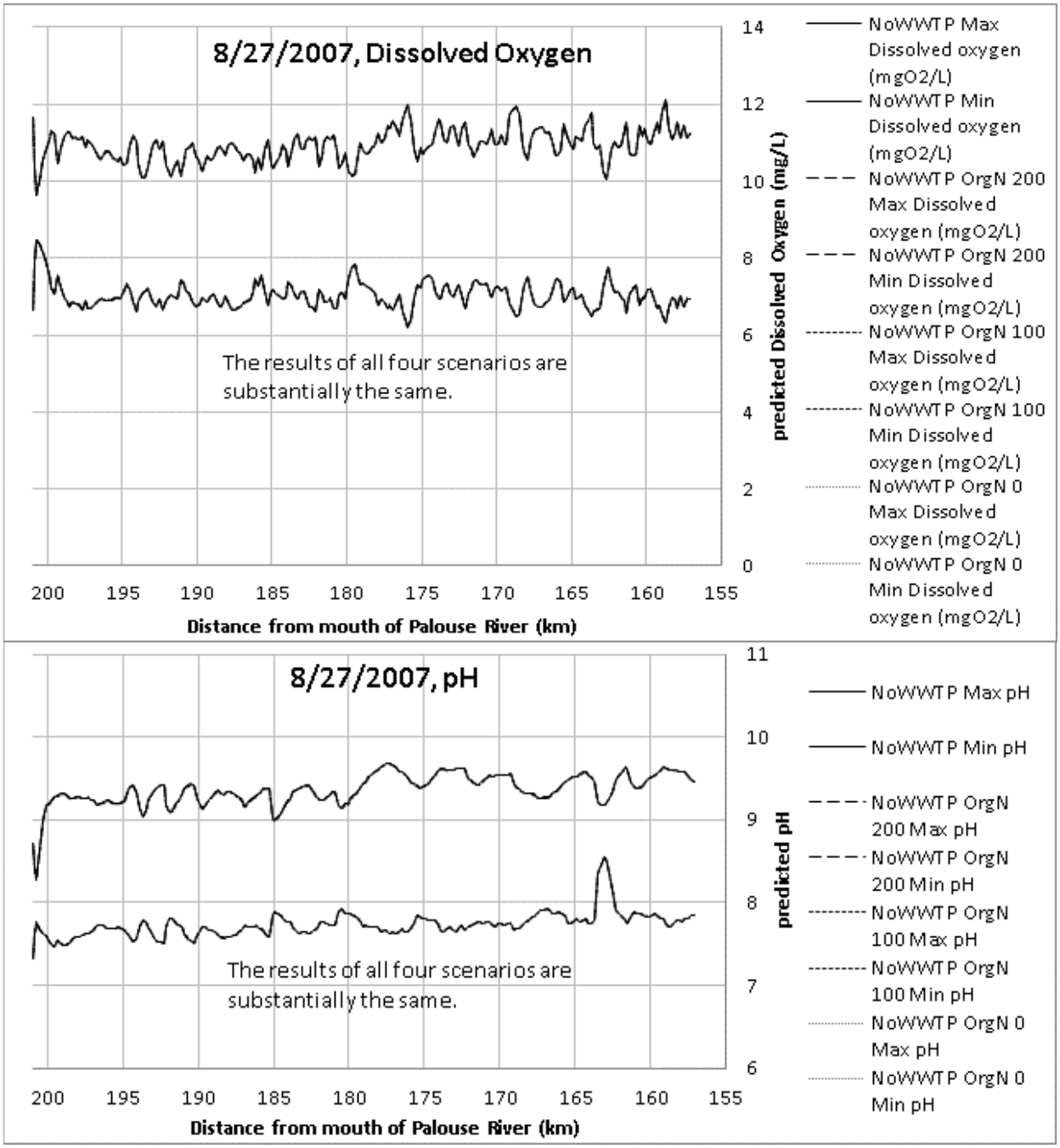
Sensitivity Analysis Scenarios

A number of model scenarios were run to test the sensitivity of model dissolved oxygen and pH predictions to key inputs. Figures C-3 – C-8 show the results of these sensitivity analyses.



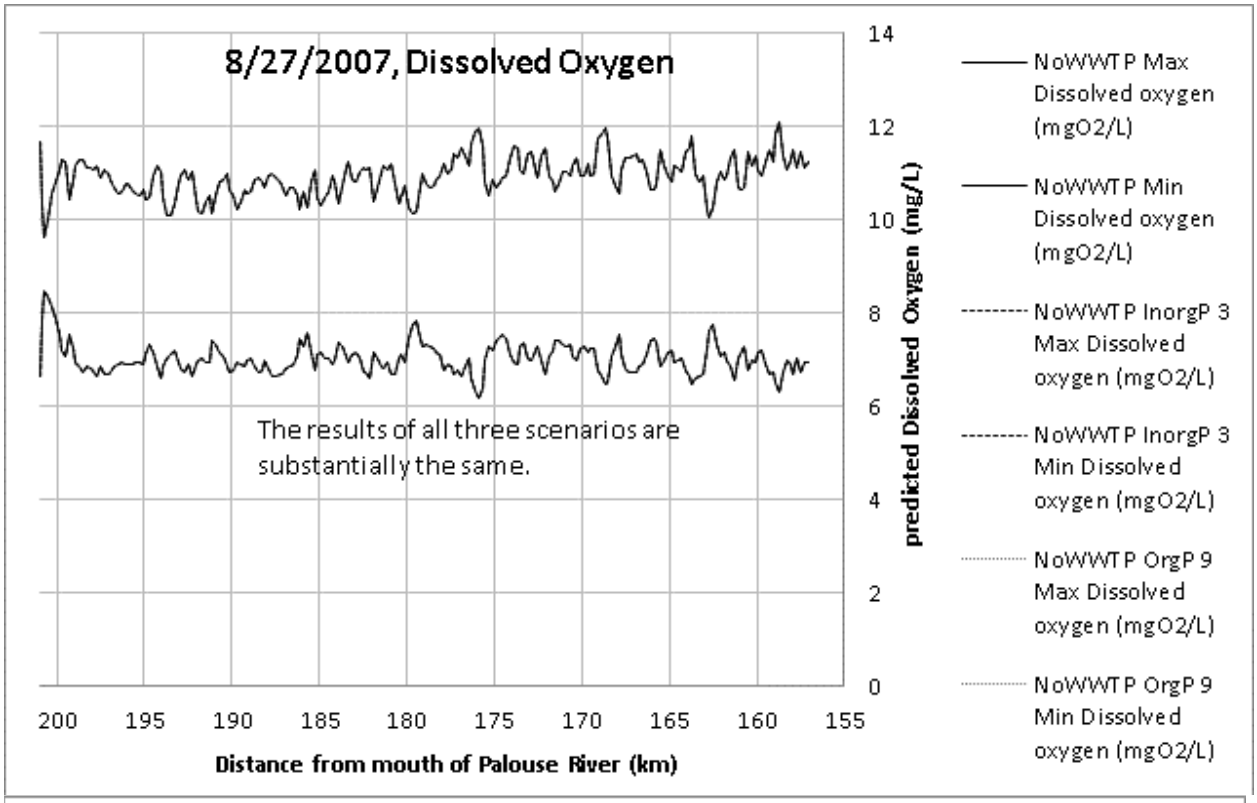
CURRENT – Current conditions for all inputs
NoWWTP – Current conditions for shade, headwater and tributaries, but no Palouse WWTP input.

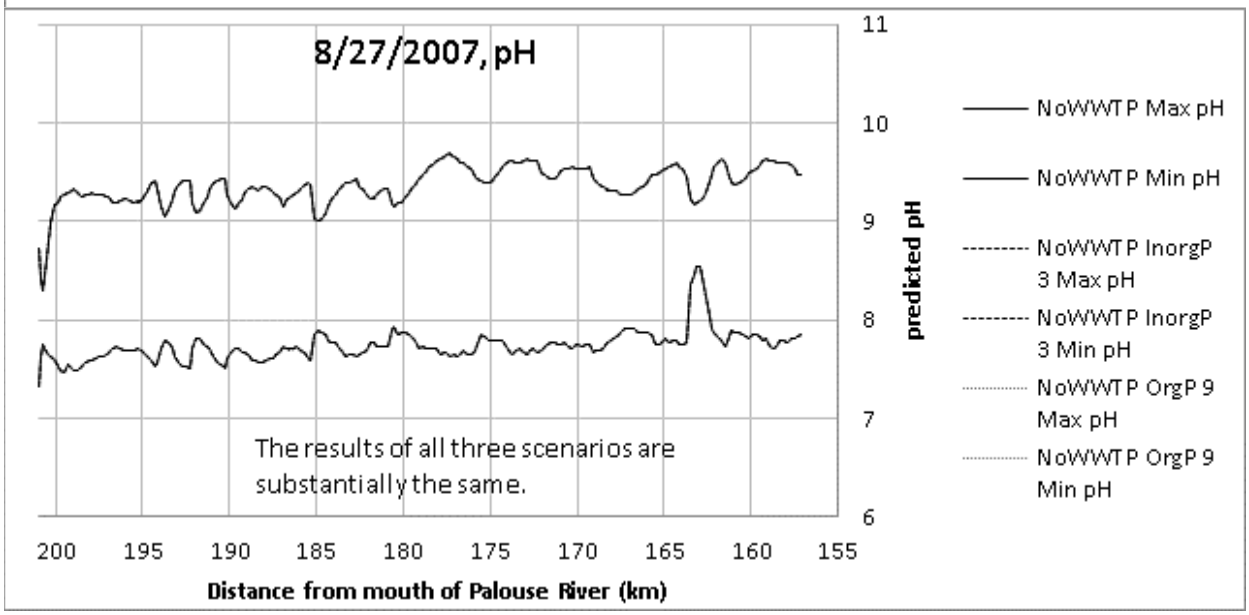
Figure C-3. Sensitivity analysis of the total effect of Palouse WWTP.



NoWWTP – Current conditions for shade, headwater and tributaries but no Palouse WWTP input.
NoWWTP OrgN 200 – Same, but with Organic Nitrogen concentration in headwater and tributaries reduced to 200 ug/L.
NoWWTP OrgN 100 – Same, but with Organic Nitrogen concentration in headwater and tributaries reduced to 100 ug/L.
NoWWTP OrgN 0 – Same, but with Organic Nitrogen concentration in headwater and tributaries reduced to 0 ug/L.

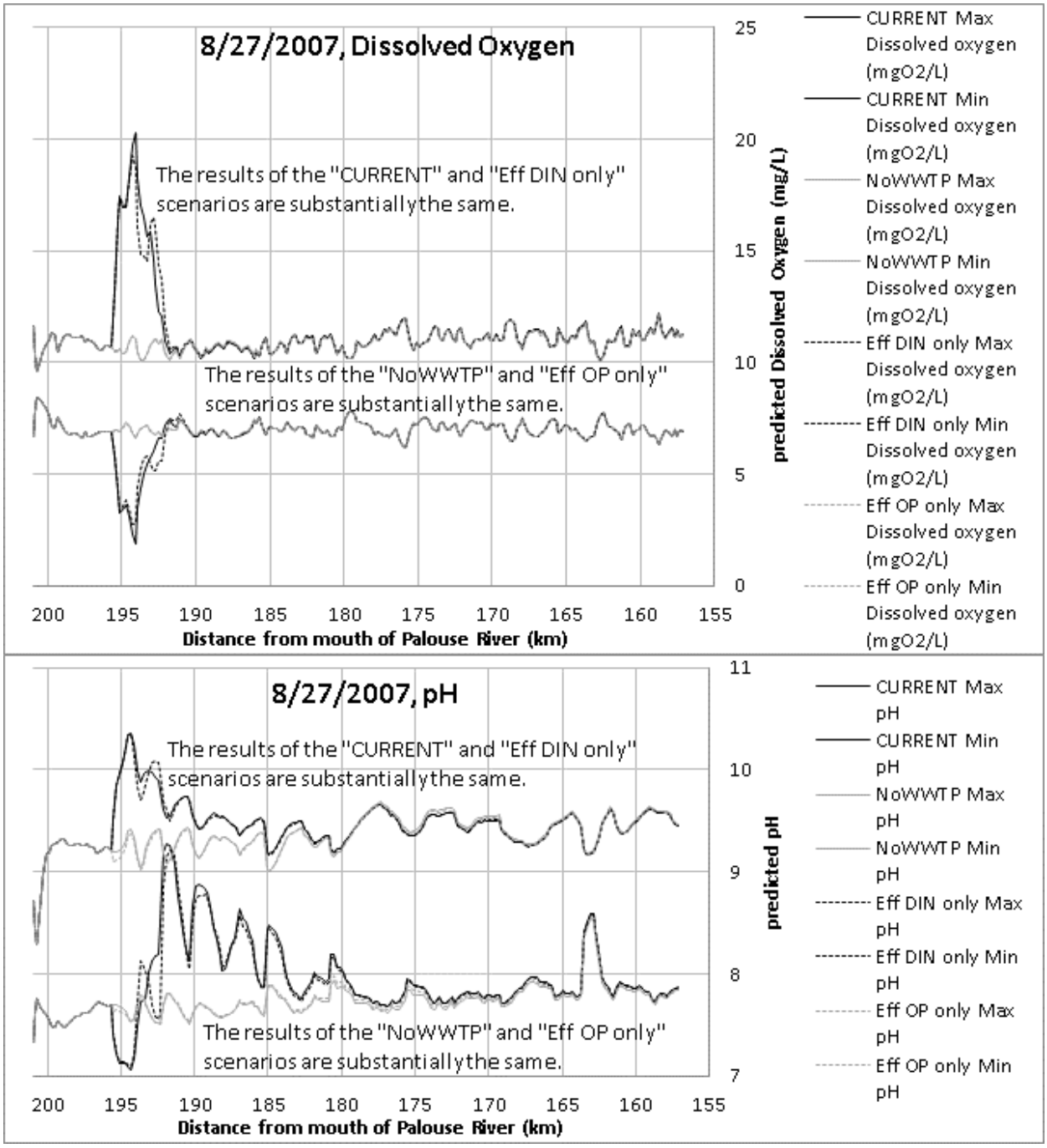
Figure C-4. Sensitivity analysis of the effect of headwater and tributary organic nitrogen concentrations.





NoWWTP – Current conditions for shade, headwater and tributaries, but no Palouse WWTP input.
NoWWTP InorgP 3 – Same, but with Inorganic Phosphorus concentration in headwater and tributaries reduced to 3 ug/L.
NoWWTP OrgP 9 – Same, but with Organic Phosphorus concentration in headwater and tributaries reduced to 9 ug/L.

Figure C-5. Sensitivity analysis of the effect of headwater and tributary phosphorus concentrations.



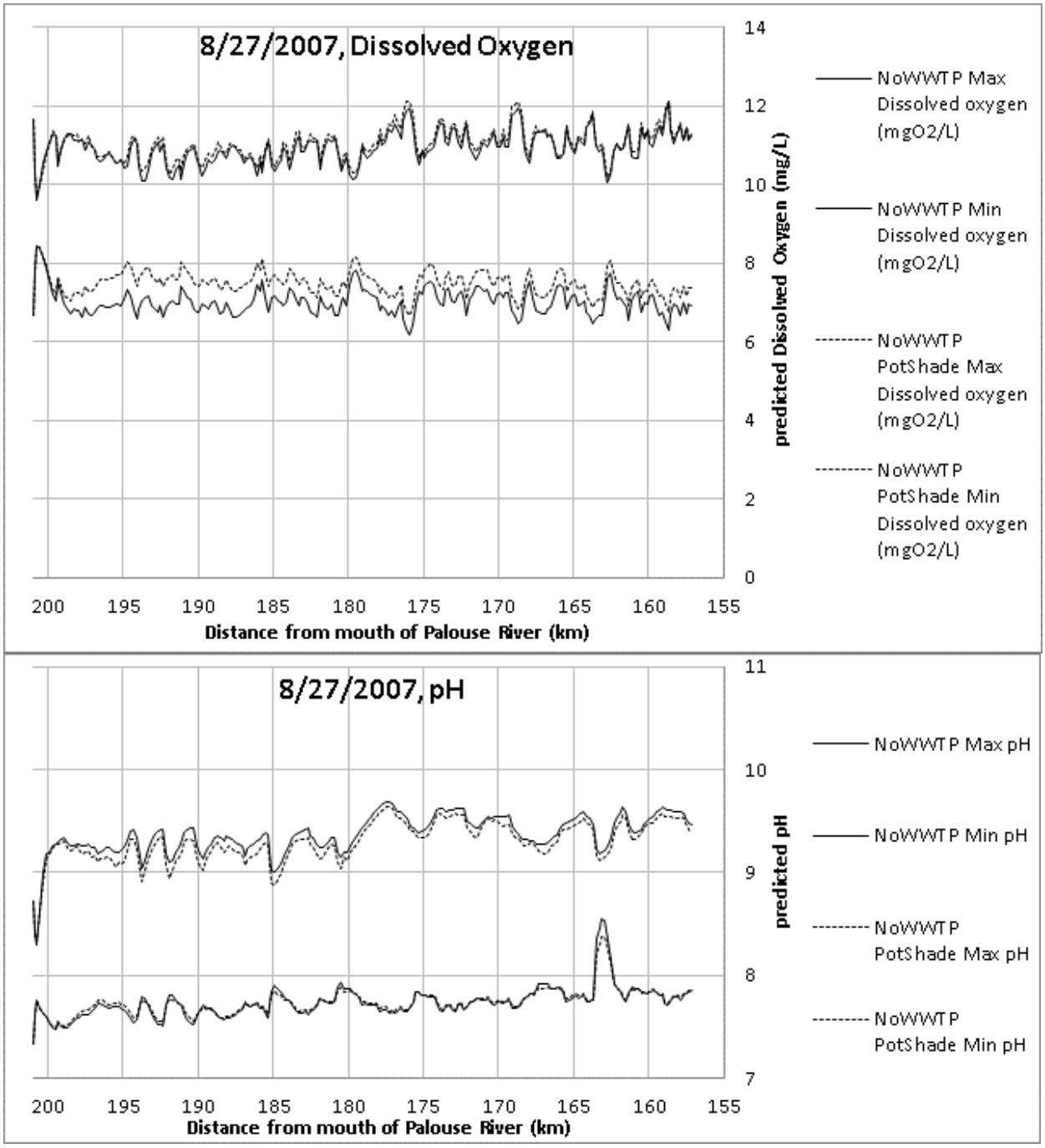
CURRENT – Current conditions for all inputs

NoWWTP – Current conditions for shade, headwater and tributaries, but no Palouse WWTP input.

Eff DIN only – Palouse WWTP effluent contains the same amounts of NO_2-NO_3 and NH_4 as under current conditions, but no other nutrients.

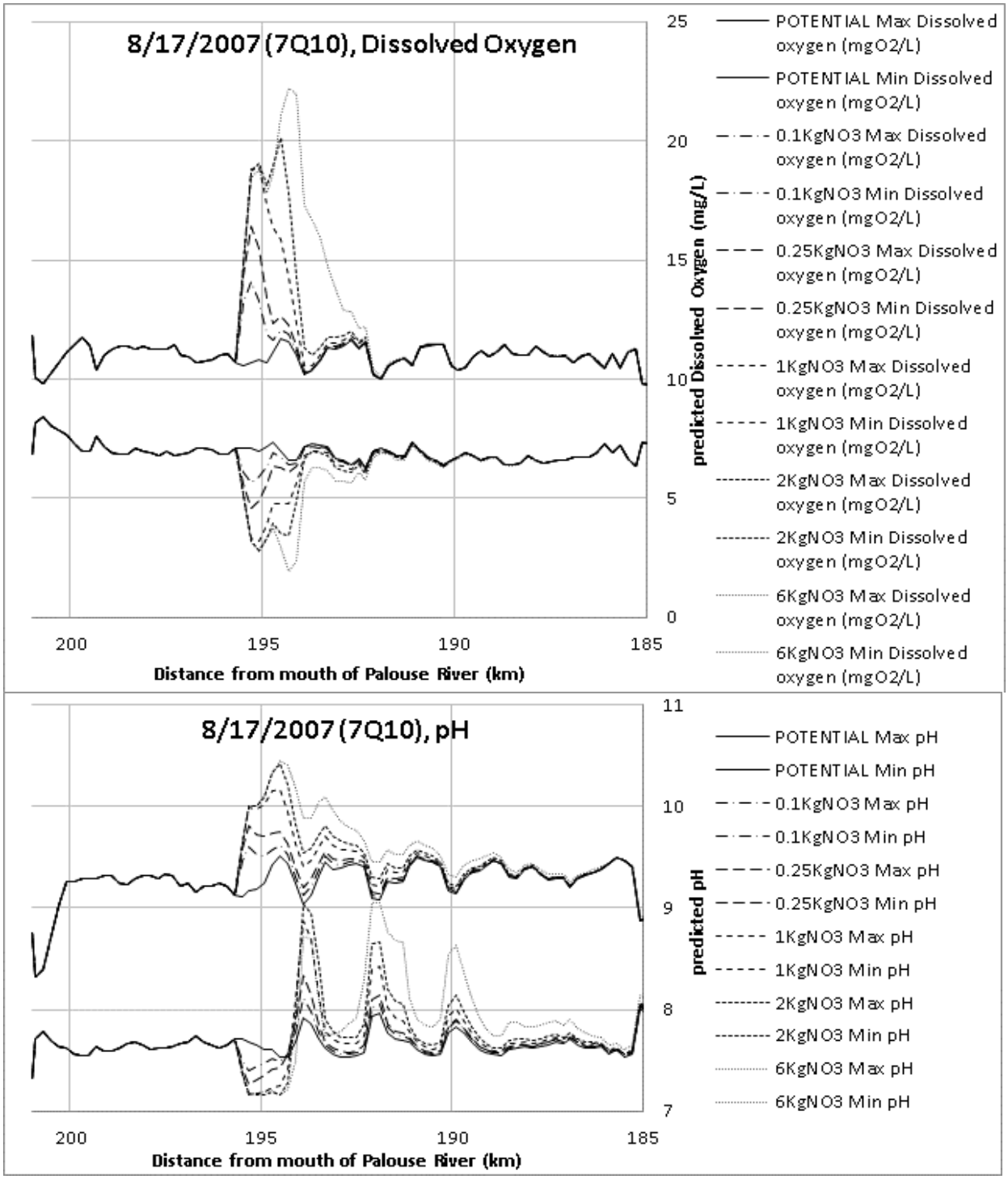
Eff OP only – Palouse WWTP effluent contains the same amounts of orthophosphate as under current conditions, but no other nutrients.

Figure C-6. Sensitivity analysis of the separate effects of nitrogen and phosphorus in Palouse WWTP effluent.



NoWWTP – Current conditions for shade, headwater and tributaries, but no Palouse WWTP input.
NoWWTP PotShade – Same, but with system potential shade (see Snouwaert and Stuart, 2013) throughout.

Figure C-7. Sensitivity analysis of the effects of shade.



Note that, unlike the other longitudinal graphs present so far, this figure does not cover the entire model domain, but just the section between the state line and approximately Altergott Rd.
All scenarios have system potential shade and boundary condition inputs. (See "System Potential Conditions" section below)
Load scenarios are nitrate as N, in Kg / day.
Current conditions typical nitrate load for August is 6.5 Kg N / day; 99.8% of DIN from Palouse WWTP is NO_2 or NO_3.

Figure C-8. Sensitivity analysis of the effects of various nitrate loads from Palouse WWTP.

The sensitivity scenarios presented above demonstrate that the QUAL2Kw model of the North Fork Palouse is very sensitive to additions of inorganic nitrogen, and insensitive to phosphorus. This is consistent with the observed nutrient ratios and uptake patterns, which indicate that the North Fork Palouse River is highly nitrogen limited.

The scenarios also show that the model is insensitive to additions of organic nitrogen. This is because it is only inorganic nitrogen that is directly usable by periphyton. Organic nitrogen must be hydrolyzed to ammonia before it can be taken up. The organic nitrogen hydrolysis rate in the model is set to 0.0019/d, which is very low. Therefore, the model predicts that changes in the concentration of organic nitrogen do not have much of an effect on periphyton growth, dissolved oxygen, or pH.

The model is somewhat sensitive to shade. Shade affects stream temperature, and most of the kinetic processes in the model have a temperature correction. Also, temperature affects the saturation point for dissolved gasses. Shade also affects light availability for periphyton and macrophyte growth.

Effect of inorganic N vs. P in Palouse WWTP effluent

The result of the sensitivity analysis of inorganic nitrogen vs. phosphorus in Palouse WWTP effluent is stark. The model predicts that, in a hypothetical scenario where the effluent contained its current load of inorganic nitrogen but no inorganic phosphorus, the impact to downstream dissolved oxygen and pH would be as great as it is with the current load of nitrogen and phosphorus. Conversely, in a hypothetical scenario where the effluent contained its current load of inorganic phosphorus but no inorganic nitrogen, the model predicts that there would be no appreciable impact to downstream dissolved oxygen and pH.

The load of inorganic nitrogen already in the river upstream of the WWTP outfall is negligible (undetectable upstream concentrations of nitrate-nitrite and ammonia). If phosphorus alone were added to the river, it is reasonable that it would not increase growth of periphyton, since the periphyton growth would still be limited by nitrogen.

On the other hand, if the current typical August load of 6.5 kg NO_3/day were discharged without any phosphorus, this would be expected to increase growth of periphyton, since there is already an upstream load of inorganic phosphorus. This upstream load of inorganic phosphorus at summer low flow is around 0.07 kg/day, which is enough to "react" with about 0.4 kg/day of NO_3. In the model, the organic phosphorus hydrolysis rate is set to 0.3/d, which provides additional inorganic phosphorus that can "react" with this effluent nitrate load, apparently enough to react with all of it.

To summarize, the results of this sensitivity analysis are partly the effect of the actual observed upstream inorganic nitrogen and inorganic phosphorus loads, and are partly the effect of the of the organic nitrogen hydrolysis and organic phosphorus hydrolysis rate parameters used in the model.

Discussion of organic nitrogen and phosphorus hydrolysis rates

As previously discussed, the sensitivity of the model to nutrient inputs is strongly affected by the organic nitrogen and organic phosphorus hydrolysis rate parameters, which reflect the rates at

which organic nitrogen and organic phosphorus are remineralized to inorganic nitrogen (specifically ammonia) and inorganic phosphorus. The hydrolysis rates used in the model are 0.0019/d for organic nitrogen, and 0.3/d for organic phosphorus. Typical literature ranges for these parameters range from 0.001/d - 0.4/d for organic nitrogen and 0.001/d – 0.8/d for organic phosphorus (EPA, 1985).

It is not possible to directly measure the rates of all the processes simulated by the model. Instead these rates have to be inferred from the observed data during the process of model calibration. During model calibration, the organic nitrogen and phosphorus hydrolysis rate parameters proved to be very important to achieving a good model fit. The calibration process involved using QUAL2Kw's auto-calibration genetic algorithm (Pelletier et al., 2006), running sets of 16 or more auto-calibration runs simultaneously. The result of this in every case was that the best model fits from each auto-calibration run had organic nitrogen hydrolysis rates very near zero (less than 0.02/d) and organic phosphorus hydrolysis rates centered on a range of values between about 0.3/d and 0.6/d. In other words, there were no combinations of rate parameters that could achieve a good model fit without the hydrolysis rates being in these particular ranges. This was especially true for the organic nitrogen hydrolysis rate.

It makes sense that the organic nitrogen hydrolysis rate must be very low. Typical measured summertime organic nitrogen concentrations in the North Fork Palouse River during 2007 were around 400 ug/L, while ammonia and nitrate-nitrite were typically not detectable (<10 ug/L) except below Palouse WWTP. That is because any inorganic nitrogen that becomes available gets taken up by periphyton right away. Furthermore, organic nitrogen concentrations showed a tendency to slightly increase downstream. This means that processes that generate organic nitrogen, such as breakdown of detritus, outpace hydrolysis of organic nitrogen to ammonia.

This points to a tendency to conserve nitrogen in its organic form. If the hydrolysis rate were higher, that would be expected to result in organic nitrogen concentrations decreasing downstream, as well as resulting in an increase of the amount of ammonia available for uptake by periphyton. Given our understanding of the extreme sensitivity of periphyton to inorganic nitrogen (see "verification of sensitivity to inorganic nitrogen" section below), a small amount of extra ammonia could make a big difference in periphyton growth, dissolved oxygen, and pH, and the marked contrast in DO and pH that is observed between the nitrogen-starved portions of the river and the enriched reach downstream of Palouse WWTP would be less.

For organic phosphorus, the hydrolysis rate is apparently higher. Concentrations of organic phosphorus tend to decrease downstream. This suggests less of a tendency to conserve phosphorus in its organic form, and more of a tendency to convert to an inorganic form than is the case with nitrogen.

Assessment of Model Sensitivity to Inorganic Nitrogen

The sensitivity analysis of the effect of various nitrate loads from Palouse WWTP demonstrates the extreme sensitivity of the model to inputs of inorganic nitrogen. The model predicts that the effect of moderate reductions of Palouse WWTP nitrate loading will be to reduce the length of river that is subject to dissolved oxygen and pH impacts, but not to reduce the critical impact very much. The model predicts that extreme reductions in nitrate load will be necessary to significantly reduce the most critical dissolved oxygen and pH impacts.

The nutrient sensitivity characteristics of the model are critical to making accurate predictions about the effects of various nutrient loads and load reductions. This characteristic of the model will directly affect the load and wasteload allocations established by the TMDL. Therefore it is crucial that the nutrient sensitivity characteristics of the model match those of the river. If the model is over-sensitive, it could result in extra money and effort being unnecessarily spent to control nutrient pollution. If the model is under-sensitive, it could result in inadequate protection of water quality.

The sensitivity of periphyton to the presence of a limiting nutrient can be conceptualized as a relationship between primary productivity and the concentration of the limiting nutrient (Figure C-9). This relationship is not linear. Rather, at low concentrations of the limiting nutrient, a small increase in limiting nutrient concentration will have a large impact on productivity. At higher concentrations, additional increases in concentration will have a smaller impact on productivity.

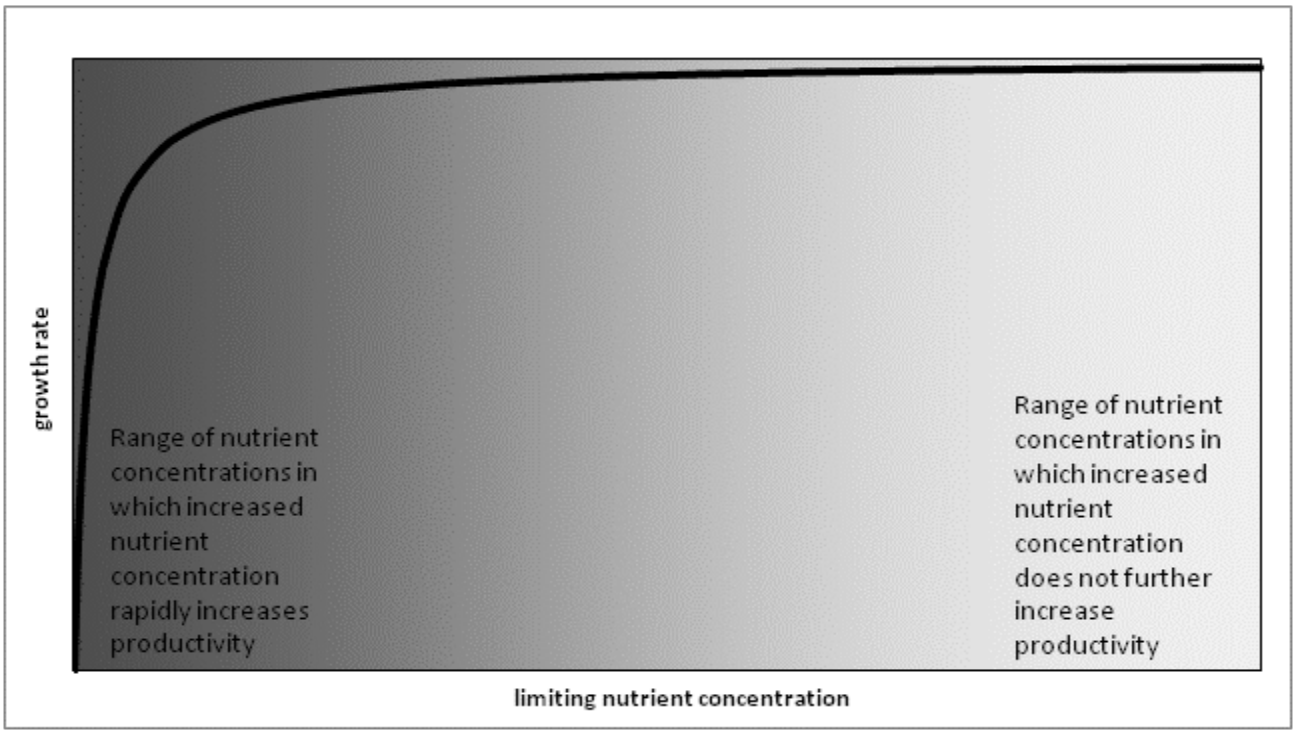


Figure C-9. Conceptual diagram of the relationship between limiting nutrient concentration and algal growth rate, using Monod equation (Monod, 1950; see Borchardt, 1996).

For the North Fork Palouse River, the relationship between inorganic nitrogen and primary productivity was established by plotting the DIN measured at various sample sites against two different measures of productivity:

1.) Measured areal periphyton biomass as chlorophyll a (mg/m^2)

2.) Gross Primary Productivity (GPP; $gO_2/m^2/day$) estimated from continuous hydrolab measurements of dissolved oxygen and pH, using the River Metabolism Analyzer (RMA) tool (Pelletier, 2013). This was done by using the Bayesian approximation function to solve for GPP, ecosystem respiration (ER), reaeration, and photosynthetic quotient (PQ). 200 model seeds were used, and the GPP parameters from the top 10 results were averaged to get an estimate of GPP.

Because the sample results from the North Fork Palouse River did not span a great range of DIN values, this analysis was extended to a portion of the mainstem Palouse River, which also had data collection occur during 2007. The portion of the mainstem Palouse River from Colfax to Rock Creek was analyzed as this reach appears to have similar nitrogen-limited characteristics as the North Fork Palouse River. The lower Palouse River below Rock Creek was not included because it appears this reach may be phosphorus-limited.

Finally, to verify the inorganic nitrogen sensitivity of the QUAL2Kw model, these curves of measured DIN vs. productivity were plotted against the daily average DIN and periphyton biomass predicted by the model.

Figure C-10 shows the QUAL2Kw model predictions of periphyton biomass vs. DIN plotted against observed periphyton biomass vs. observed DIN. Figure C-11 shows the same QUAL2Kw model predictions of periphyton biomass vs. DIN plotted against GPP estimates from RMA vs. observed DIN.

Figures C-10 and C-11 demonstrate that the relationship between DIN and primary productivity in the North Fork Palouse does follow the conceptual curve shown in Figure C-9, although the relationship is not as clean. Particularly at higher DIN values where productivity is no longer nutrient-limited (nutrient saturation), there is a range of productivity levels that may occur, apparently from about 13 to 25 $gO_2/m^2/day$. Lower levels of productivity occur only at very low DIN concentrations.

Table C-10 presents more details of the RMA simulation results, along with corresponding nutrient data.

The modeled and observed productivity vs. DIN curves are in good agreement, both with respect to the range of productivity levels that occur at nutrient saturation, and with respect to the DIN concentrations that limit productivity. Therefore the model can be expected to reliably predict the dissolved oxygen and pH effects of different nitrogen loads.

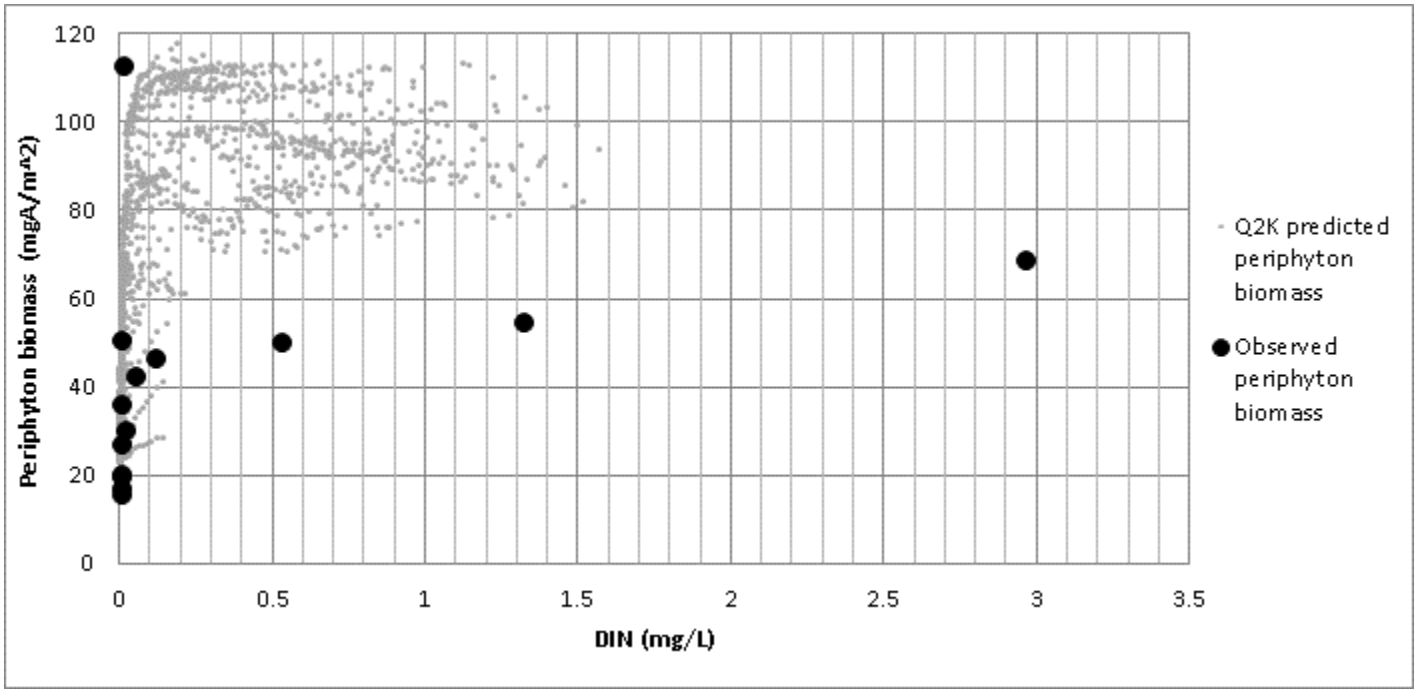


Figure C-10. Modeled periphyton biomass vs. DIN and observed periphyton biomass vs. DIN

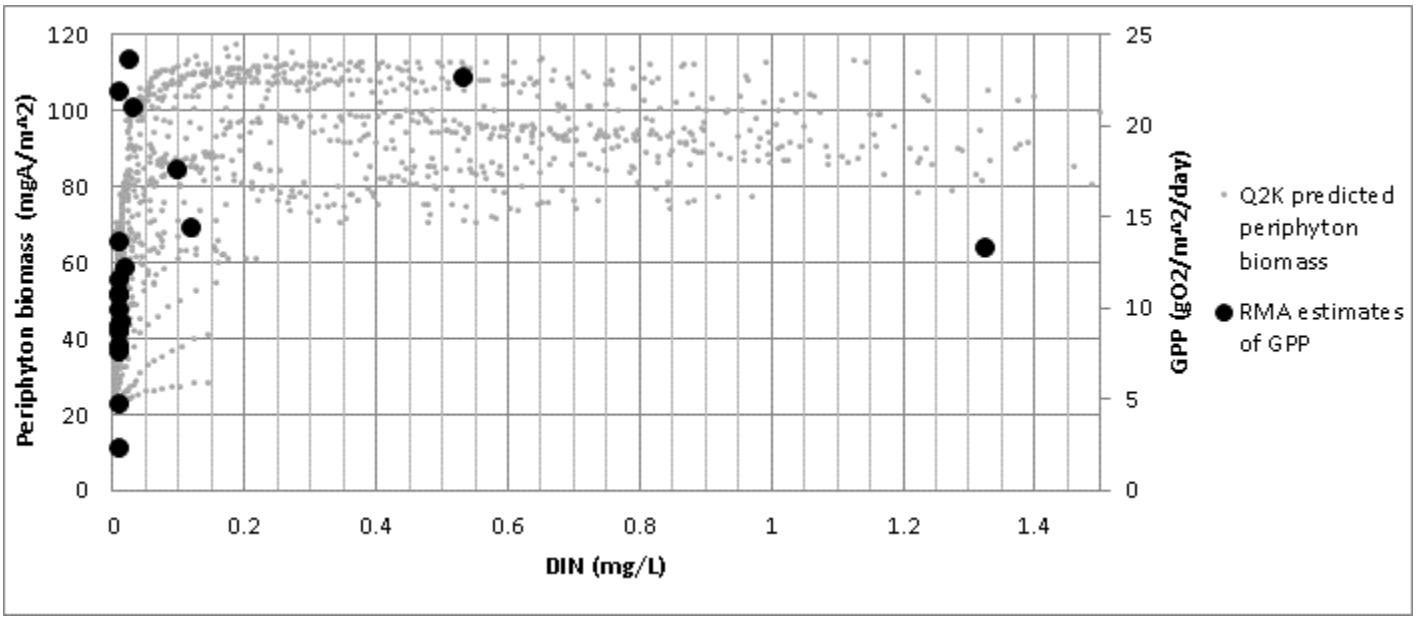


Figure C-11. Modeled periphyton biomass vs. DIN and RMA estimates of GPP vs. observed DIN

For both figures 32 and 33, non-detect values of observed DIN, i.e. where both ammonia and nitrate-nitrate values were non-detects, are plotted as 0.01 mg/L. Actual values could range from 0 to 0.02 mg/L. For instances where either ammonia or nitrate-nitrite was a non-detect, but not both, DIN is calculated as 0.005 mg/L for the non-detect parameter plus the detected result for the other.

Table C-10. RMA simulation results used for assessing QUAL2Kw model sensitivity to inorganic nitrogen.

Diel dataset		Corresponding nutrient data				RMA predictions		
Site	Synoptic	NH_4 (mg/L)	$N0_3$ (mg/L)	Total DIN (mg/L)	OP (mg/L)	GPP (gO_2/m^2/ day)	ER (gO_2/m^2/ day)	Ka (/d)
PAL124.3	July	**0.005**	**0.005**	0.01	0.041925	11.527	10.512	0.948
PAL112.4	July	**0.005**	**0.005**	0.01	0.041925	10.771	9.641	10.046
PAL103.9	July	**0.005**	**0.005**	0.01	0.0145	10.679	8.429	12.731
PAL98.3	July	0.015	**0.005**	0.02	0.016	12.161	11.283	14.828
PAL85.6	July	**0.005**	**0.005**	0.01	0.609	8.648	11.291	3.224
PAL77.8	July	**0.005**	**0.005**	0.01	0.389	13.647	10.302	8.167
PAL66.8	July	**0.005**	0.095	0.1	0.1815	17.507	14.969	6.929
PAL59.0	July	**0.005**	**0.005**	0.01	0.147	2.318	6.915	5.453
PAL49.5	July	0.01025	0.022625	0.032875	0.0996375	21.001	18.095	8.043
PAL41.1	July	0.0075	**0.005**	0.0125	0.0135	9.188	8.245	10.553
PAL124.3	August	**0.005**	**0.005**	0.01	0.007475	4.734	3.959	0.384
PAL118.9	August	**0.005**	0.5295	0.5345	0.0832	22.613	16.923	3.903
PAL112.4	August	**0.005**	**0.005**	0.01	0.013	7.93	7.244	10.713
PAL103.9	August	**0.005**	**0.005**	0.01	0.0024	7.551	6.064	13.103
PAL98.3	August	**0.005**	**0.005**	0.01	0.00275	8.955	8.387	16.101
PAL85.6	August	0.015	1.31	1.325	0.8345	13.294	9.327	2.521
PAL77.8	August	**0.005**	**0.005**	0.01	0.444	21.796	19.078	10.327
PAL66.8	August	0.0105	0.11	0.1205	0.0939	14.391	12.288	6.487
PAL49.5	August	0.007	0.02025	0.02725	0.0417625	23.563	19.925	13.688
PAL41.1	August	**0.005**	**0.005**	0.01	0.0135	9.834	8.863	11.128

BOLD indicates a non-detect. Values shown are half the detection limit.

System Potential Conditions Model Inputs

To simulate dissolved oxygen and pH under system potential conditions, the QUAL2Kw model was re-run with some of the inputs modified to reflect conditions that did not include human pollutant sources or shade loss. Unlike the calibration model runs, for which part of the season represented 2007, part of it 2012, and part of it 1987, the system potential conditions model run was based entirely on 2007. Therefore, the first step was to replace the 2012 and 1987 inputs for the September portion of the model run with inputs representing 2007. Then the model was verified against all available data from September, mainly flow and temperature, to make sure that it continues to accurately predict 2007 data through September.

Table C-11 shows the changes that were made to model inputs to represent system potential conditions.

Table C-11. Model inputs used to represent system potential conditions

Model inputs constituents or inputs not listed in this table were assumed to be the same under system potential conditions as under current conditions.

Constituent or input	Input value or time-series, data source, and/or rationale
Miscellaneous inputs	
Palouse WWTP (all inputs)	No input (no WWTP effluent)
Meteorology	Pullman Airport, 2007 conditions.
Shade	System potential shade (Snouwaert and Stuart, 2013).
Main channel upstream and tributary boundary conditions	
Flow	2007 conditions. 2007 was a 7Q10 year.
Temperature	*Upstream boundary conditions*: Output of rTemp (Pelletier, 2004) model for potential vegetation conditions at Bridge St. (34PAL120.3; Snouwaert and Stuart, 2013). *Tributaries*: Output of rTemp model for potential vegetation conditions at mouth of Silver Ck. (34SIL00.0).
Dissolved oxygen	Same quasi-empirical (for upstream) and empirical (for tributaries) models used for current condition dissolved oxygen inputs, but calculated using system potential temperatures as defined above.
Organic Nitrogen[23]	Capped at **179 ug/L**. This is equivalent to the 25th percentile of TPN measurements at Bridge St. (34A170) taken during July-October. This compares to TKN-NH_4 result of 180 ug/L at upper watershed sites upstream of Laird Park in Idaho during 1994 (Greene et al., 1997). This also compares to EPA recommendations for reference conditions for TN-NO_2-NO_3 of 80 to 180 ug/L for the Northern Rockies ecoregion (EPA, 2000a) and 149 to 288 ug/L for the Columbia Plateau ecoregion (EPA, 2000b).
Ammonia Nitrogen	**0 ug/L**
Nitrate-Nitrite Nitrogen	**0 ug/L**
Organic Phosphorus[23]	**16.4 ug/L**. Calculated as 22-5.6, where 22 ug/L is the 25th percentile of TP measurements at Bridge St. (34170) taken during July-October, and 5.6 ug/L represents the inorganic phosphorus fraction (see below). This compares to TP-OP result of 10 ug/L at upper watershed sites upstream of Laird Park in Idaho during 1994 (Greene et al., 1997). This also compares to EPA recommendations for reference conditions for TP of 7.75 ug/L for the Northern Rockies ecoregion (EPA, 2000a) and 30 ug/L for the Columbia Plateau ecoregion (EPA, 2000b).
Inorganic Phosphorus[23]	**5.6 ug/L**. This is equivalent to the 25th percentile of OP measurements at Bridge St. (34A170) taken during July-October. This compares to OP result of 20 ug/L at upper watershed sites upstream of Laird Park in Idaho during 1994 (Greene et al., 1997).
pH	*Upstream boundary conditions*: Same empirical model used for current condition pH inputs, but calculated using system potential temperatures as defined above. *Tributaries*: **7.75 S.U.** (same as current conditions)

[23] In many TMDLs, system potential condition boundary condition nutrient concentrations are a critical factor in determining TMDL outcomes. It is important to reiterate that in this case, the model (and almost certainly the river) is insensitive to nutrient fractions other than ammonia, nitrate, and nitrite (DIN). Therefore the organic nitrogen, organic phosphorus, and inorganic phosphorus inputs do not matter. See "Sensitivity Analysis Scenarios" section above.

Appendix D. Breeding's Addition Model Scenario

During both the July 30-31, 2007 and August 27-28, 2007 surveys, round-the-clock high pH values were observed in the Palouse River at Bridge St. (34PAL120.3), which is located upstream of the Palouse WWTP outfall (Figure D-1, at 196 km). One explanation is that there could be a high-productivity reach upstream of this station. However, there are no documented sources of nutrients between the state line and Bridge St. that might explain this. Streamflows during the 2007 surveys were slightly lower than those encountered in September 2012, and the weather conditions were warmer.

During the September 17-19, 2012 survey, which included additional sites upstream of Bridge St., pH values observed at and upstream of Bridge St. showed diel fluctuations typical of most of the river. No evidence of any upstream nutrient inputs was seen at that time. If there was an undocumented source of nutrients near the upstream end of the City of Palouse during 2007, it may be that it was eliminated since that time.

One explanation for these pH data is that homes in Breeding's addition, located at the far east edge of Palouse, may have been contributing nutrients to the river via septic systems located on shallow soil over basalt bedrock. Drain field discharges could percolate down to bedrock and then run along the surface of bedrock down to the river. During 2007-2008, the City of Palouse extended the city sewer system to Breeding's addition and connected 5 homes. If these homes were the source of these nutrients, this may explain why no evidence of a source was found during the 2012 survey.

The QUAL2Kw model can be used to test this hypothesis. Figure D-1 presents two pH simulations for August 27, 2007. The first scenario only includes documented nutrient sources (mainly Palouse WWTP). The second scenario also includes a hypothetical source, located adjacent to Breeding's addition, equivalent to effluent from five typical septic tanks[24]. This scenario shows that this hypothetical source is consistent with observed pH data. Although it cannot be conclusively proved, the city may well have eliminated a significant impact to dissolved oxygen and pH by extending its sewer network.

[24] Source flow = 0.000030 cms (equivalent to 1.25% of Palouse WWTP effluent; proportional based on 5 out of 402 occupied houses in city of Palouse).
Ammonia N = 120 mg/L.
Nitrate/Nitrite = 40 mg/L.
Inorganic phosphorus = 15.75 mg/L. (Total N and P values from Charles et al., 2005; fraction proportions from Withers et al., 2011.)

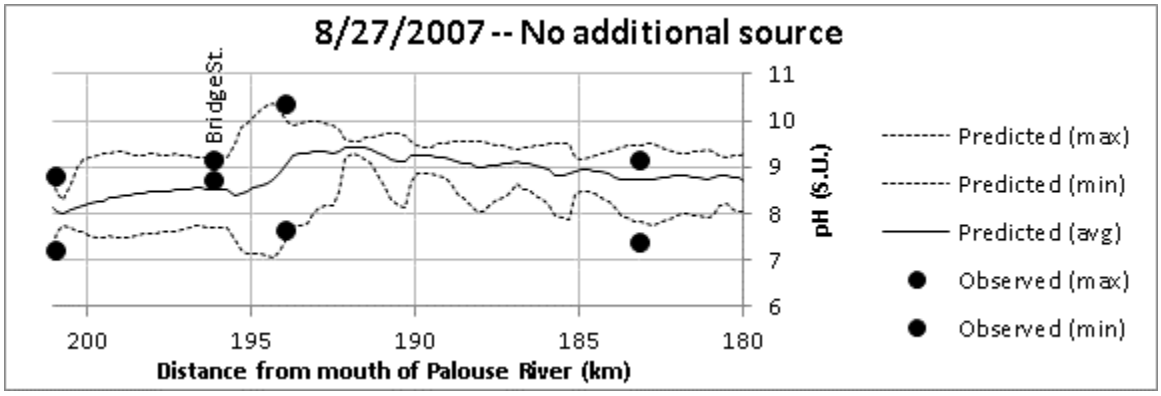


Figure D-1. pH predicted by the QUAL2Kw model for August 27, 2007, showing the effect of a hypothetical nutrient source adjacent to Breeding's Addition.