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# Water Quality Conditions on the Williamson River Delta, Oregon: Four Years Post-Restoration

## 2011 Annual Data Report

**Natanya Hayden and Heather Hendrixson**
**The Nature Conservancy**
**Klamath Basin Field Office**
**226 Pine St., Klamath Falls, Oregon**

**March 1, 2012**

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## SUMMARY OF RESULTS

- Site water depths were 0.3-0.7 m higher during the 2011 sampling year compared to 2010. Earlier years (2008 and 2009), had similar lake levels to 2011. Williamson River mean daily discharge was considerable higher in 2011 compared to the past 93 year mean.
- Total phosphorus concentrations were highest in the seasonally flooded Tulana emergent and transitional wetlands during the majority of the year, compared to all other locations in the project area. Phosphorus concentrations in 2011 were slightly lower in emergent wetlands than observed concentrations in 2010 and 2009. Phosphorus levels were generally comparable in deep water and open water wetlands, as well as lake sites between 2009–2011. However, early restoration years (2007 and 2008) had a greater concentration of phosphorus in permanently flooded areas of Tulana (open and deep water wetlands) compared to 2009–2011 trends.
- Total nitrogen concentrations in the permanently flooded wetlands and in Upper Klamath and Agency Lake sites appeared to have an inverse relationship with seasonal trends in chlorophyll-*a* concentration. Total nitrogen peaked twice in deep water and open water wetlands during late July and early September, while chlorophyll-*a* peaked only once between seasonal highs in nitrogen (late August). This trend was about 2–3 weeks delayed compared to 2008–2010 years, which typically experienced two peaks in nitrogen in mid/late July and mid/late August.
- Endangered Lost River (*Deltistes luxatus*) and shortnose (*Chasmistes brevirostris*) suckers' habitat had fewer occurrences of water quality threshold exceedances in 2011 compared to previous years. Particularly, high stress thresholds for DO ($<4$ mg $L^{-1}$) and pH ($<9.7$) have gradually decreased from 2008 to 2011. In 2011, only 6% of the total hours recorded was below critical DO levels, compared to 21% of the time in 2008.

## INTRODUCTION

The Nature Conservancy (TNC) has monitored water quality on the Williamson River Delta (the Delta) for four years following restoration in 2007. The primary goals of wetland restoration were to: (1) promote and improve water quality in Upper Klamath and Agency Lakes by eliminating a continuous agricultural source of nutrients into the lake, and by nutrient sequestration through wetland ecosystem processes; and (2) restore habitat for two endangered species of sucker endemic to the Upper Klamath Basin—the Lost River (*Deltistes luxatus*) and shortnose (*Chasmistes brevirostris*) sucker. A post-restoration water quality monitoring effort was initiated in 2007. Evaluating surface water quality was designed to address these overarching objectives: (1) measure the extent to which the wetlands provide a source or sink of phosphorus and nitrogen; (2) assess the effects of the restoration on surface water chemistry within the wetlands and adjacent lakes; and (3) evaluate water quality conditions that may have been detrimental to endangered suckers. A two-year comprehensive report for 2007-2009 (Wong et al. 2010) and annual reports for 2008 (Doehring et al. 2009), 2009 (Doehring et al. 2010), and 2010 (Wong et al. 2011) have been completed. This report summarizes water quality data collected in the Delta in 2011 and year comparisons of water chemistry trends for the period 2007-2011.

## STUDY AREA

The Delta encompasses 7,500 acres located between Upper Klamath and Agency Lakes in southern Oregon, east of the Cascade Range (Figure 1). These wetlands surround the last four miles of the Williamson River, reducing water levels within the river prior to it flowing into Upper Klamath Lake. Before 1940 this freshwater wetland system was naturally functioning with connected hydrology. However, beginning in 1940 the wetlands were drained and converted for agriculture. The entire Delta's hydrology was disconnected from Upper Klamath and Agency Lakes. Additionally, the Williamson River was separated through the construction of levees along the Delta perimeter. TNC initiated a large-scale restoration effort in 1996 and recently completed restoration with the breaching of levees west of the Williamson River (known as Tulana) in October 2007 and east of the river (known as Goose Bay) in November 2008. Approximately 5,500 acres were re-flooded, restoring the wetlands as an open and passively managed system.

Four breaches ranging about 2,100–2,700 feet in length are located on the northwest and southwest perimeters of Tulana. Three breaches ranging about 1,000–3,000 ft in length are located on the south perimeter of Goose Bay. Three breaches ranging 500–1,700 ft are also situated along the Williamson River on both the Tulana and Goose Bay sides. Between breaches, levees were lowered to a surface elevation ranging 4,139–4,142 ft.

Hydrology within the Delta wetlands is dependent on that of Upper Klamath and Agency Lakes and the Williamson River. Lake levels are regulated by the US Bureau of Reclamation and fluctuate ±5 feet throughout the year, with highs (~4,143 ft surface water elevation) typically in April and lows (~4,138 ft surface water elevation) typically in October. At seasonally high water levels, water overflows the majority of remaining perimeter levees. During seasonally low water levels, the wetlands are largely cut off from lake and river flows except through the perimeter breaches. Significant soil subsidence has occurred on western portions of the Delta such that current elevations in these areas are as much as 8 feet below average lake elevations (David Evans and Associates, Inc. 2005). Currently these areas result in open water conditions year-round. Hydrologic seasonal trends include: (1) late spring and early summer flooding of emergent and riparian wetlands in eastern portions of Tulana and in the majority of Goose Bay, (2) followed by receding water levels and subsequent drying out of these sites in late summer and fall, and (3) year-round inundation in the western areas of Tulana.

Vegetation across the Delta wetlands is largely influenced by water depth and flooding tolerances of various plant species. Documentation of species composition and coverage are available in TNC's vegetation monitoring report for the Delta (Elseroad et al. 2011). Four distinct habitat zones comprised of different plant communities occur along a gradient across the Delta wetlands. From shallowest to deepest, these include: transitional wetlands, emergent wetlands, deep water wetlands, and open water (Elseroad 2004; Figure 1). Transitional and emergent wetlands are the more densely vegetated habitat zones, and deep water wetlands and open water are the less or non-vegetated zones. Within the transitional and emergent sites, vegetation was abundant during the 2011 sampling season, primarily a factor of seasonal inundation lasting into late summer.

## METHODS

### Sampling Locations

All sampling sites were fixed sites which have been monitored for surface water quality since 2008 in Tulana and 2009 in Goose Bay. In 2011, a total of 27 sites were sampled, including 4 sites in 4 habitat zones in Tulana (open water, deep water, emergent, and transitional wetlands), 3 sites in 2 habitat zones in Goose Bay (emergent and transitional wetlands), 3 sites near-shore of the Delta perimeter in Upper Klamath and Agency Lakes, and 2 sites in the Williamson River (one upstream and one near the mouth before it enters Upper Klamath Lake; Figure 1). Sampling sites in the emergent wetlands were discontinued on August 23, 2011 as water levels declined and sites became too shallow to sample. Sites in transitional wetlands were not sampled after July 13, 2011 in Tulana and July 27, 2011 in Goose Bay, due to low water levels. Nutrients and parameters collected at each site are shown in Table 1.

Multi-probe instruments (YSI 600 XLM sondes) were deployed at a subset (9) of the 27 fixed grab sampling sites, including 1 in 4 habitat zones in Tulana (open water, deep water, emergent, and transitional), 1 in Goose Bay in the emergent wetlands, 1 in the Williamson River upstream of the project area, and 3 in the lakes near-shore of the Delta perimeter.

### Grab Sampling

Surface water grab samples were collected for constituents of nitrogen (N), phosphorus (P), carbon (C), and chlorophyll-*a* (chl-*a*). Nitrogen and P samples were collected at all 27 sites sampled over 16 sampling events from March–November 2011. Carbon and chl-*a* samples were collected at 21 of the 27 sites from April–late September 2011. Carbon was sampled over 6 events, while chl-*a* was collected over 12 events.

Field methods were similar to previous monitoring years and followed protocols detailed in TNC's Quality Assurance Project Plan (The Nature Conservancy 2008). At sites less than 1 m water depth, water was collected at mid-depth in the water column. At sites between 1–2 m deep, water was collected at mid-depth in the water column and at 0.5 m below the water surface. Sites greater than 2 m deep were sampled at 0.5 and 1 m below the water surface. Water was collected with a Van Dorn and mixed using a churn splitter before being transferred to triple-rinsed sample bottles. Quality assurance samples were also collected during each sampling event. Quality assurance results for nutrients and chl-*a* are presented in Appendix A. All water samples were stored in a cooler on ice at ~4°C until further processed. Other site data collected included water depth, water transparency (secchi depth), surface algal bloom (algal density measured on a 0–5 scale), and vegetation composition. Ambient water temperature, dissolved oxygen (DO) concentration, pH, and specific conductivity were also measured instantaneously at each site using a YSI 600 XLM sonde.

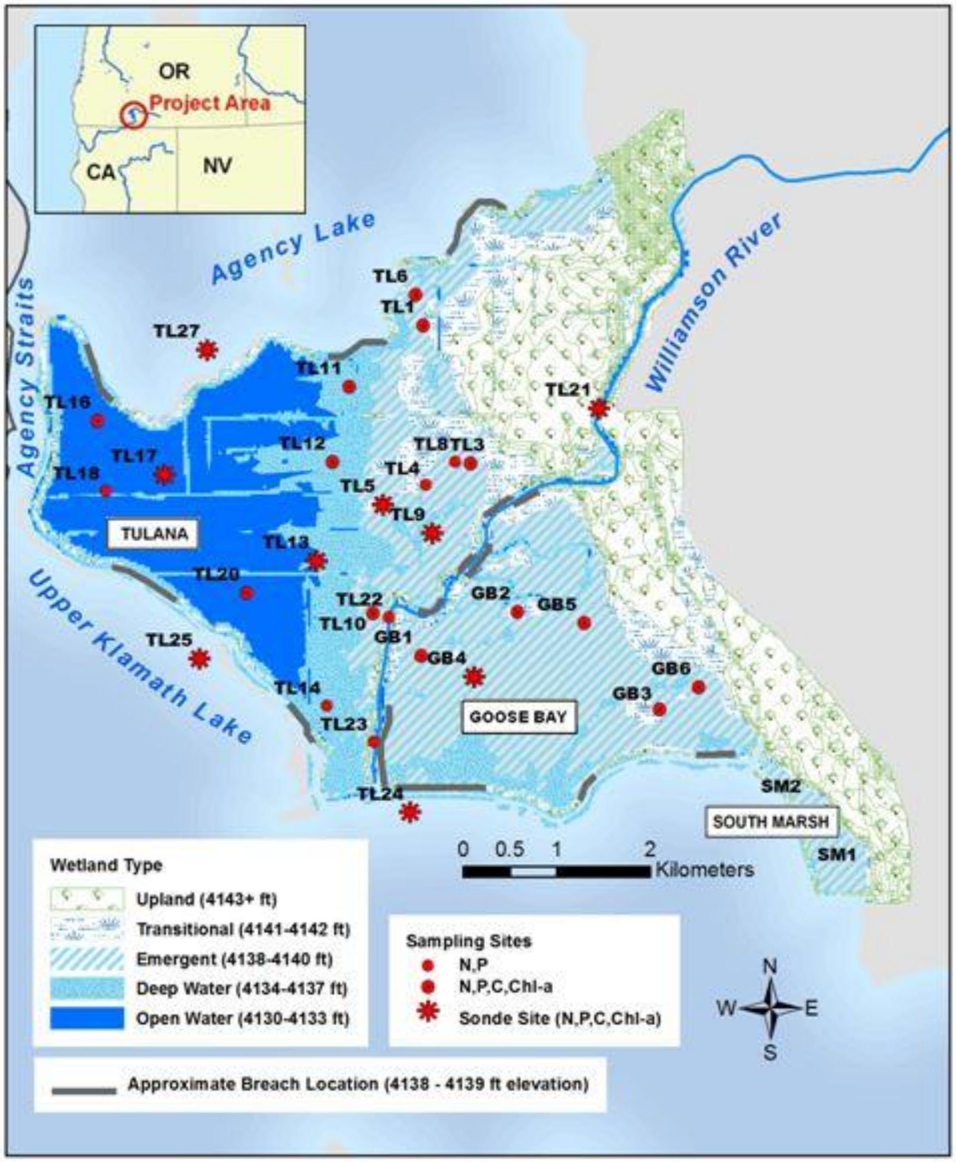


**Figure 1. Map of the Williamson River Delta, Oregon showing wetland habitat types and water sampling sites 2011.**

**Table 1. Water quality data collected at each water sampling site in the Williamson River Delta project area in 2011. 'Sonde' denotes water temperature, dissolved oxygen concentration, pH, and specific conductivity. 'X' denotes sample collected and '-' denotes sample not collected.**

| Location | Site ID | Habitat | Sonde | Nitrogen | Phosphorus | Carbon | Chlorophyll-a |
|---|---|---|---|---|---|---|---|
| | | | Hourly | 16 events | | 6 events | 12 events |
| | | | March-November | | | April-September | |
| Tulana | TLTR1 | Transitional Wetland | - | X | X | X | X |
| | TLTR3 | Transitional Wetland | - | X | X | X | X |
| | TLTR4 | Transitional Wetland | - | X | X | - | - |
| | TLTR5 | Transitional Wetland | X | X | X | X | X |
| | TLEM6 | Emergent Wetland | - | X | X | X | X |
| | TLEM8 | Emergent Wetland | - | X | X | - | - |
| | TLEM9 | Emergent Wetland | X | X | X | X | X |
| | TLEM10 | Emergent Wetland | - | X | X | X | X |
| | TLDW11 | Deep Water Wetland | - | X | X | X | X |
| | TLDW12 | Deep Water Wetland | - | X | X | X | X |
| | TLDW13 | Deep Water Wetland | X | X | X | X | X |
| | TLDW14 | Deep Water Wetland | - | X | X | - | - |
| | TLOW16 | Open Water | - | X | X | X | X |
| | TLOW17 | Open Water | X | X | X | X | X |
| | TLOW18 | Open Water | - | X | X | - | - |
| | TLOW20 | Open Water | - | X | X | X | X |
| Goose Bay | GBTR1 | Transitional Wetland | - | X | X | X | X |
| | GBTR2 | Transitional Wetland | - | X | X | X | X |
| | GBTR3 | Transitional Wetland | - | X | X | X | X |
| | GBEM4 | Emergent Wetland | X | X | X | X | X |
| | GBEM5 | Emergent Wetland | - | X | X | X | X |
| | GBEM6 | Emergent Wetland | - | X | X | X | X |
| River | WR21 | Williamson River, upstream | X | X | X | X | X |
| | WR23 | Williamson River, downstream | - | X | X | - | - |
| Lake | UKLE24 | Upper Klamath Lake, nearshore | X | X | X | - | - |
| | UKLW25 | Upper Klamath Lake, nearshore | X | X | X | X | X |
| | AL27 | Agency Lake, nearshore | X | X | X | X | X |

## Laboratory Analysis

Samples for analysis of N and P were brought to the Klamath Tribes' Sprague River Water Quality Laboratory in Chiloquin, Oregon immediately from the field. Nitrogen and P constituents included total nitrogen (TN), nitrate and nitrite ($NO_X$), ammonium ($NH_4$), total phosphorus (TP), and orthophosphate ($PO_4$). For analysis of TN and TP, approximately 120 mL of unfiltered sample water were transferred to triple-rinsed amber polyethylene bottles and acidified with 1 mL of 4.5N $H_2SO_4$. Samples for analysis of $NO_X$, $NH_4$, and $PO_4$ were filtered through 47 mm, 0.45 µm sterile membrane filters (Millipore®) using a vacuum pump and 300 mL magnetic filter funnel (Pall Gelman ®). All N and P samples were stored at 4°C (±2°C) for less than 28 days. Total P and TN samples were digested using potassium persulfate, autoclaved, then analyzed on an automated spectrophotometer. Analyses of samples for $PO_4$, $NO_X$, $NO_2$, and $NH_4$ were completed using the colorimetric method on an automated spectrophotometer (see Appendix B for Standard Method references).

Carbon samples were shipped on ice overnight and analyzed by Basic Laboratory, Inc. in Redding, California. Carbon constituents included total organic carbon (TOC) and dissolved organic carbon (DOC). Total organic C samples were pre-preserved with 4.5N $H_2SO_4$, and DOC samples were filtered prior to analysis. Carbon samples were analyzed using the persulfate-ultraviolet oxidation method (see Appendix B). Chloropyll-*a* samples were pre-preserved with 4.5N $H_2SO_4$ and shipped on ice overnight to be analyzed by Aquatic Research, Inc. in Seattle, Washington.

Detection and reporting limits for nutrient constituents and chl-*a* are shown in Appendix B. Concentrations less than the detection limit were analyzed at half the detection limit value.

### Continuous Monitoring

Hourly water temperature, DO, pH, and specific conductivity data were collected using YSI 600XLM sondes deployed at nine fixed sites in the project area from March–November 2011. Sondes were placed at mid-depth in the water column or at 1 m below the water surface if water depth exceeded 2 m.

Upper Klamath Lake elevation levels and Williamson River flow data was monitored by US Geological Survey (USGS). Water level and flow data were obtained from the USGS online database system and are provisional, subject to revision.

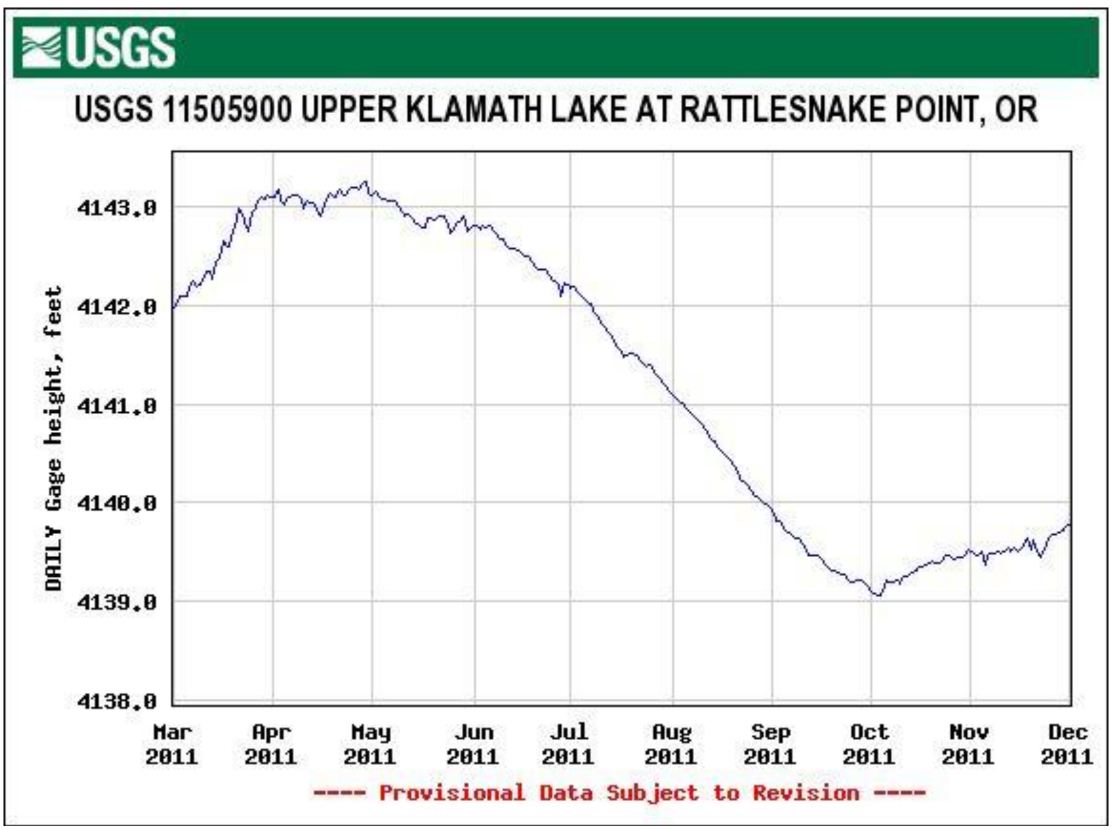


**Figure 2. Upper Klamath Lake daily water levels from March-December 2011. Data collected at Rattlesnake Point, OR by USGS.**

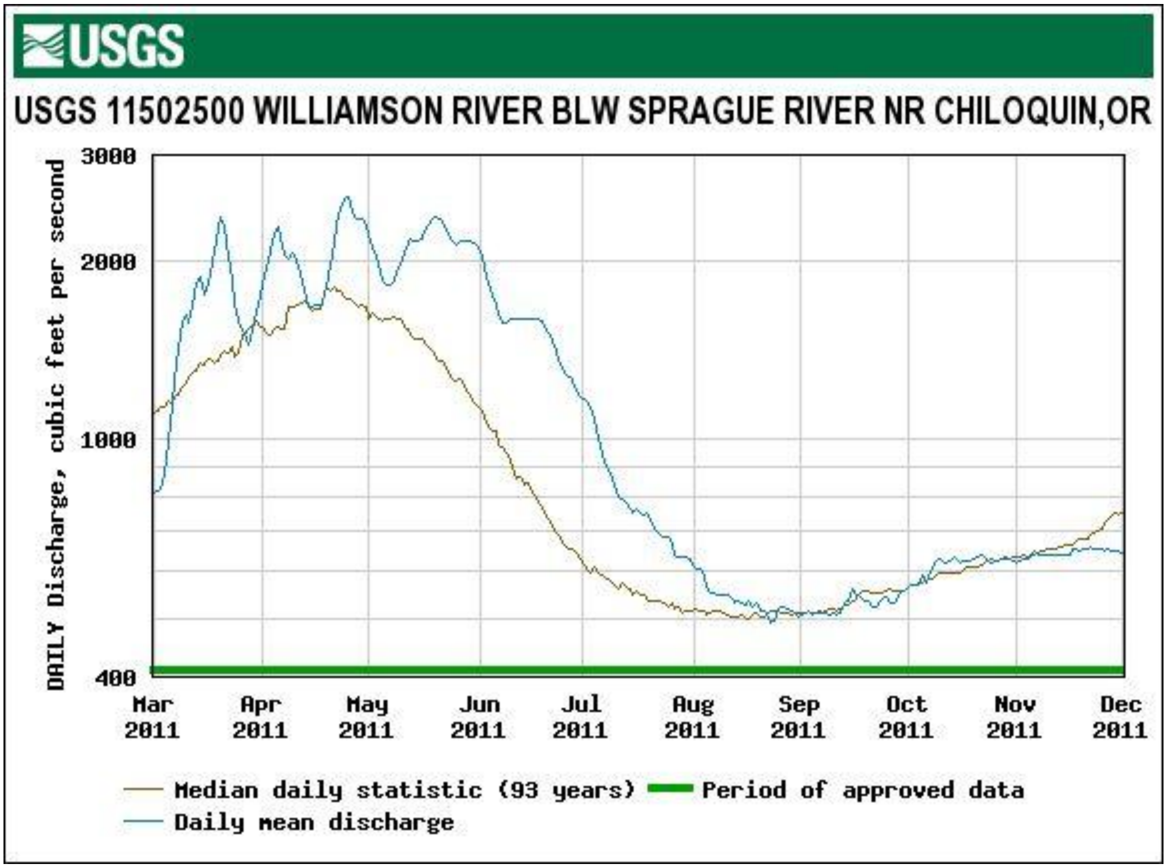


**Figure 3. Daily mean discharge levels compared to daily median over the last 93 years for Williamson River from March-December 2011. Data collected by USGS at site 11502500 on Williamson River below Sprague River near Chiloquin, OR.**

Quality assurance checks included weekly calibration of instruments, weekly site visits, and post-calibration checks. Calibration was performed the day prior to deployment of individual sondes. Weekly site visits included the following: precision checks of deployed sondes against a newly calibrated reference sonde; cleaning of deployed sondes; and re-deployment or replacement of sondes such that an individual sonde was deployed at a site for no longer than two-week intervals. Post-calibration checks were performed to verify accuracy of each sonde following a deployment. Data quality objectives adhered to requirements defined in the Quality Assurance Project Plan (The Nature Conservancy 2008). TNC's quality assurance criteria for acceptable continuous monitor data are shown in Appendix C, and quality assurance results are reported in Appendix D. All raw data were quality-checked before being accepted for statistical analysis. Daily statistics were computed only for days in which at least 20 hours of acceptable data were recorded. Statistics were generated using SAS© System for Windows, Release 9.1.3 (SAS Institute).

## RESULTS

Measured site water depths ranged from 0.2-1.0 m in the transitional, 0.25–1.5 m in the emergent wetlands, 1.0–2.8 m in the deep water wetlands, 1.5–3.1 m in open water, and 0.8–2.5 m in the lakes over the sampling year. River depths remained considerably higher comparatively, ranging from 2.7-4.6 m throughout the sampling period. Maximum water depths within all wetland habitat types in 2011 were 0.2–0.5 m higher than maximum water depths in 2010 (1.0 m in the emergent wetlands, 2.3 m in the deep water wetlands, and 2.7 m in open water in 2010). 2010 was an unusually low water level year in the Delta; maximum water depths in 2011 were similar to seasonal trends observed in previous sampling years (2008 and 2009). Nutrients, chlorophyll-a, and continuous monitoring parameters are reported in the following text. Both seasonal ranges for 2011 and post-restoration inter-annual trends (2007-2011) are presented in the results.

## Grab Sampling

Phosphorus

In total, 348 P and N samples were collected in 2011. Total P concentrations ranged from 0.05–1.54 mg $L^{-1}$ among wetland sites, 0.04–0.50 mg $L^{-1}$ among lake sites, and 0.08–0.16 mg $L^{-1}$ among river sites during the sampling period March–November 2011 (Table 2). On average over the year, $PO_4$ comprised about 55% of TP in the wetlands, 50% in lakes, and 60% in the river.

Among habitat types, mean TP concentrations were highest in the Tulana transitional wetlands during most sampling events from March–July (mean TP=0.37 mg $L^{-1}$), while TP concentrations were lowest in the Williamson River (mean TP=0.10; Figure 4a). Among emergent wetland locations, mean TP concentrations were about twice as high in Tulana (0.29 mg $L^{-1}$) compared to Goose Bay emergent wetland concentrations (0.15 mg $L^{-1}$). Mean TP concentrations in Tulana emergent and transitional wetlands started increasing considerably in mid June and reached maximal levels in mid and late July. Deep water, open water, lake sites, and Goose Bay emergent sites all peaked later in the season, reaching their highest levels throughout August and September, and then declining through November.

Compared to previous years of monitoring, ranges in TP and $PO_4$ concentrations were generally lower in 2011 in transitional and emergent wetlands when compared to 2008–2010. This trend was strongest in Goose Bay (Figure 5a and 5b). Overall, TP and $PO_4$ have gradually decreased each subsequent year proceeding restoration. Deep water wetlands, open water wetlands, and lake sites had drastically higher TP and $PO_4$ concentrations in 2008 immediately following levee removal and reflooding of previously agricultural land. However, concentrations between 2009 through 2011 have been relatively similar. River concentrations have been consistent between sampling years, with 2009 being the exception, where TP was doubled during July-August. Similarly, $PO_4$ was highest in 2008 and 2009 during July (Figure 5b).

Nitrogen

Total N concentrations ranged from 0.05–6.36 mg $L^{-1}$ among wetland sites, 0.10–4.55 mg $L^{-1}$ among lake sites, and 0.09–0.62 mg $L^{-1}$ among river sites (Table 2). On average over the year, dissolved inorganic nitrogen (DIN; the sum of $NO_X$ and $NH_4$ concentrations) comprised about 1.7–5.8% of TN among wetland sites, 5.1% among lake sites, and 6.6% of TN at river sites.

Mean TN concentrations in the open water and deep water wetlands peaked two times in late July and early September (Figure 4a). In the lake sites TN peaked only once in late August. Both emergent wetlands sites, as well at Goose Bay transitional wetlands and Williamson River sites all had consistently low levels of TN throughout the sampling year. Alternatively, Tulana transitional wetlands' TN concentration rose steadily throughout June and July; sampling in this habitat area was discontinued after July due to decreasing water levels inhibiting monitoring. Ammonium and $NO_X$ concentrations in the wetlands and lakes increased significantly in mid-September through the end of sampling period in November (Figure 4a). During October–November, DIN comprised a greater majority of TN (40% among wetland sites, 35% among lake, and 15% among river sites) compared to the average range over the year.

Total N concentrations in transitional and emergent wetlands were lowest in 2011, compared to previous years (Figure 5c). Similar to the trend observed with TP, TN gradually decreased at these sites for 4 years post-restoration. Previous peaks in emergent and transitional wetland TN (2009 and 2010), which have occurred during May, were not observed during 2011. Total N concentrations were also lower in deep water and open water wetlands in 2011, albeit to a lesser extent. Concentrations of TN in these sites have been in a similar range from 2008 through 2011. Total N has exhibited an inter-annual trend of peaking during August and September in open water and deep water sites, considerably later in the season than shallow wetlands. Lake and river sites have remained consistent between years and habitat types. Ranges and trends in $NO_X$ concentrations in 2011 were within range of values and similar to trends observed in 2008-2010 (Figure 5d). During all monitoring years the highest $NO_X$ concentrations have been consistently observed in deep water, open water, and lake sites. Ranges in $NH_4$ concentrations were lowest in 2011 throughout all habitat types; this trend was strongest in transitional and emergent wetlands (Figure 5e). Ammonium in 2011 failed to exhibit any of the seasonal peaks during later summer and early fall that characterized the 2008 and 2009 sampling years. Similarly, there was little $NH_4$ variation during 2010.

Carbon

In 2011, a total of 102 C samples were collected. Total organic C concentrations ranged from 3.7–19.0 mg $L^{-1}$ among wetland sites, 5.1–13.2 mg $L^{-1}$ among lake sites, and 1.5–7.2 mg $L^{-1}$ among river sites (Table 2). On average over the year, DOC comprised the majority of TOC in all habitats (85%). Carbon concentrations were highest from late July through late August at deep water wetlands, open water, lake sites, and Tulana emergent wetlands (Figure 4b). Goose Bay emergent and transitional wetlands deviated from this trend as C levels increased until sampling was discontinued due to receding water levels in late July (transitional) and late August (emergent). From April to the beginning of July, Tulana transitional wetland sites had the highest TOC and DOC concentrations, respectively. The Williamson River had the lowest C compared to other habitats from July through October.

Both TOC and DOC concentrations in 2011 were generally within range of values observed in previous years. General seasonal trends within habitat types have shown little inter-annual variation (Figures 5f and 5g).

Chlorophyll-a

A total of 208 chl-*a* samples were collected and analyzed in 2011. Chlorophyll-a concentrations ranged from 0.05–528 µg $L^{-1}$ in the wetlands, 2.7–320 µg $L^{-1}$ in the lakes, and 0.05–2.7 µg $L^{-1}$ in the river (Table 2).

Trends between wetland habitats in 2011 were drastically different (Figure 4a). Overall chl-*a* levels were highest in deep water wetlands, where concentrations increased by a factor of 118 from July 13, 2011 (2.7 µg $L^{-1}$) to July 27, 2011 (320 µg $L^{-1}$), maximal levels were reached on August 23, 2011 (528 µg $L^{-1}$), and then decreased by the end of September (66 µg $L^{-1}$). A similar peak was observed during August sampling in lake sites and open water wetlands. Other wetland types had significantly lower chl-*a* concentrations throughout the 2011 sampling period.

Tulana transitional wetlands reached a maximum of 75 µg $L^{-1}$ (7 times less than levels witnessed in deep water sites) and Tulana emergent wetlands peaked at 54 µg $L^{-1}$. Goose Bay transitional and emergent wetlands maintained consistently low chl-*a* throughout the entire sampling year comparatively (peaks of 11 and 21.15 µg $L^{-1}$). River sites had the lowest overall chl-*a* concentrations, never exceeding 2.7 µg $L^{-1}$.

Across year comparisons indicate chl-*a* was lower in emergent and transitional wetlands in 2011 than in previous years. Only 1 peak in total algal biomass and primary productivity (as represented by chl-*a*) was observed in 2011, compared to 2 peaks in early post-restoration years, such as 2008 and 2009 (Figure 5h).

Among all habitats, TN concentration followed trends in chl-*a* concentration and was positively correlated to chl-a (Figure 4a). Peak timings in DIN concentrations (i.e., $NO_X$ and $NH_4$) generally corresponded to lows in chl-a during the period July–September (Figure 4a).

**Table 2. Median, minimum, and maximum concentrations of grab sampling constituents by location during the 2011 sampling year, Williamson River Delta, OR.**

| | Total Phosphorus (mg $L^{-1}$) | | | Orthophosphate (mg $L^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Location/Habitat** | **Med** | **Min** | **Max** | **Med** | **Min** | **Max** |
| Tulana- Emergent Wetland | 0.19 | 0.07 | 1.54 | 0.10 | 0.01 | 1.10 |
| Tulana- Deep Water Wetland | 0.12 | 0.06 | 0.58 | 0.05 | 0.01 | 0.31 |
| Tulana- Open Water | 0.13 | 0.05 | 0.62 | 0.055 | 0.01 | 0.27 |
| Tulana- Transitional Wetland | 0.21 | 0.09 | 1.50 | 0.14 | 0.03 | 1.17 |
| Goose Bay- Emergent Wetland | 0.12 | 0.06 | 0.39 | 0.06 | 0.01 | 0.30 |
| Goose Bay- Transitional Wetland | 0.11 | 0.07 | 0.252 | 0.06 | 0.01 | 0.17 |
| Williamson River | 0.09 | 0.08 | 0.16 | 0.06 | 0.03 | 0.09 |
| Lake Sites | 0.10 | 0.04 | 0.50 | 0.04 | 0.00 | 0.60 |
| | **Total Nitrogen (mg $L^{-1}$)** | | | **Nitrate+Nitrite (mg $L^{-1}$)** | | |
| **Location/Habitat** | **Med** | **Min** | **Max** | **Med** | **Min** | **Max** |
| Tulana- Emergent Wetland | 0.62 | 0.31 | 3.35 | <0.008 | <0.008 | 0.081 |
| Tulana- Deep Water Wetland | 0.86 | 0.05 | 5.04 | 0.009 | <0.008 | 0.332 |
| Tulana- Open Water | 1.13 | 0.46 | 6.36 | 0.008 | <0.008 | 0.325 |
| Tulana- Transitional Wetland | 0.69 | 0.35 | 2.82 | <0.008 | <0.008 | 0.034 |
| Goose Bay- Emergent Wetland | 0.53 | 0.27 | 1.21 | <0.008 | <0.008 | 0.017 |
| Goose Bay- Transitional Wetland | 0.46 | 0.30 | 1.33 | <0.008 | <0.008 | 0.012 |
| Williamson River | 0.32 | 0.09 | 0.62 | 0.009 | <0.008 | 0.032 |
| Lake Sites | 0.77 | 0.10 | 4.55 | 0.008 | <0.008 | 0.231 |
| | **Ammonium (mg $L^{-1}$)** | | | **Total Organic Carbon (mg $L^{-1}$)** | | |
| **Location/Habitat** | **Med** | **Min** | **Max** | **Med** | **Min** | **Max** |
| Tulana- Emergent Wetland | 0.006 | <0.006 | 0.330 | 5.8 | 3.7 | 17.7 |
| Tulana- Deep Water Wetland | 0.013 | <0.006 | 0.263 | 7.4 | 5.2 | 18.6 |
| Tulana- Open Water | 0.018 | <0.006 | 0.194 | 9.0 | 5.2 | 19.0 |
| Tulana- Transitional Wetland | 0.006 | <0.006 | 0.100 | 7.5 | 4.3 | 14.9 |
| Goose Bay- Emergent Wetland | <0.006 | <0.006 | 0.023 | 6.4 | 5.3 | 8.4 |
| Goose Bay- Transitional Wetland | <0.006 | <0.006 | 0.013 | 5.8 | 5.2 | 7.0 |
| Williamson River | 0.010 | <0.006 | 0.030 | 4.0 | 1.5 | 7.2 |
| Lake Sites | 0.013 | <0.006 | 0.202 | 7.8 | 5.1 | 13.2 |
| | **Dissolved Organic Carbon (mg $L^{-1}$)** | | | **Chlorophyll-a (µg $L^{-1}$)** | | |
| **Location/Habitat** | **Med** | **Min** | **Max** | **Med** | **Min** | **Max** |
| Tulana- Emergent Wetland | 5.3 | 3.2 | 15.2 | 6.4 | 0.1 | 54 |
| Tulana- Deep Water Wetland | 6.3 | 4.5 | 10.6 | 21 | 0.1 | 528 |
| Tulana- Open Water | 7.5 | 4.9 | 11.7 | 27.5 | 0.1 | 493 |
| Tulana- Transitional Wetland | 6.4 | 3.8 | 12.1 | 7.5 | 1.1 | 75 |
| Goose Bay- Emergent Wetland | 5.9 | 4.3 | 7.2 | 3.2 | 0.1 | 21.2 |
| Goose Bay- Transitional Wetland | 5.2 | 4.3 | 6.1 | 3.0 | 0.1 | 11 |
| Williamson River | 3.7 | 1.0 | 6.0 | 0.8 | 0.1 | 2.7 |
| Lake Sites | 6.4 | 4.7 | 10.4 | 25 | 2.7 | 320 |

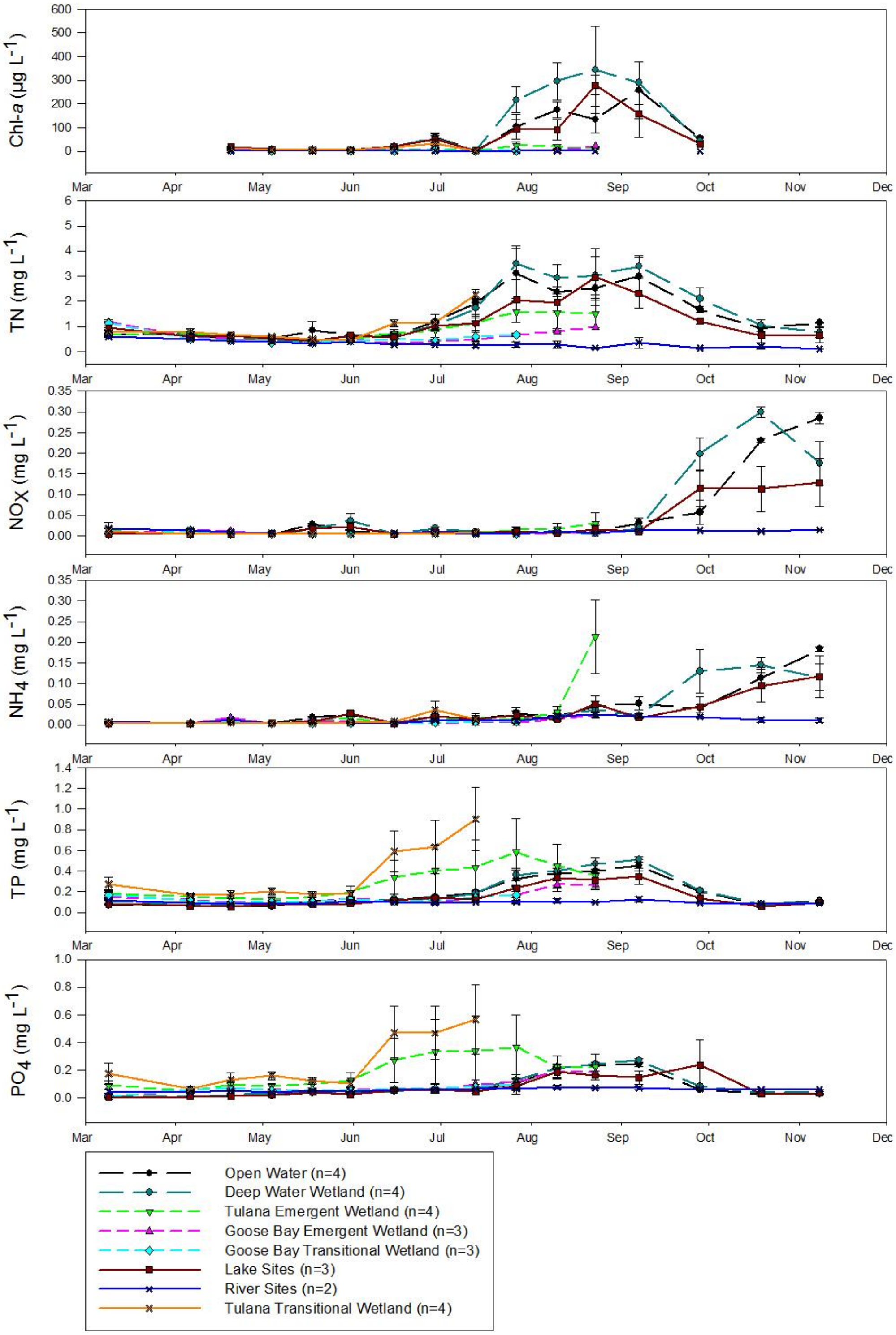


**Figure 4a. Seasonal trends in grab sample constituents, Williamson River Delta, OR, 2011. Shown are means (± standard error) by location/habitat and sampling event.**

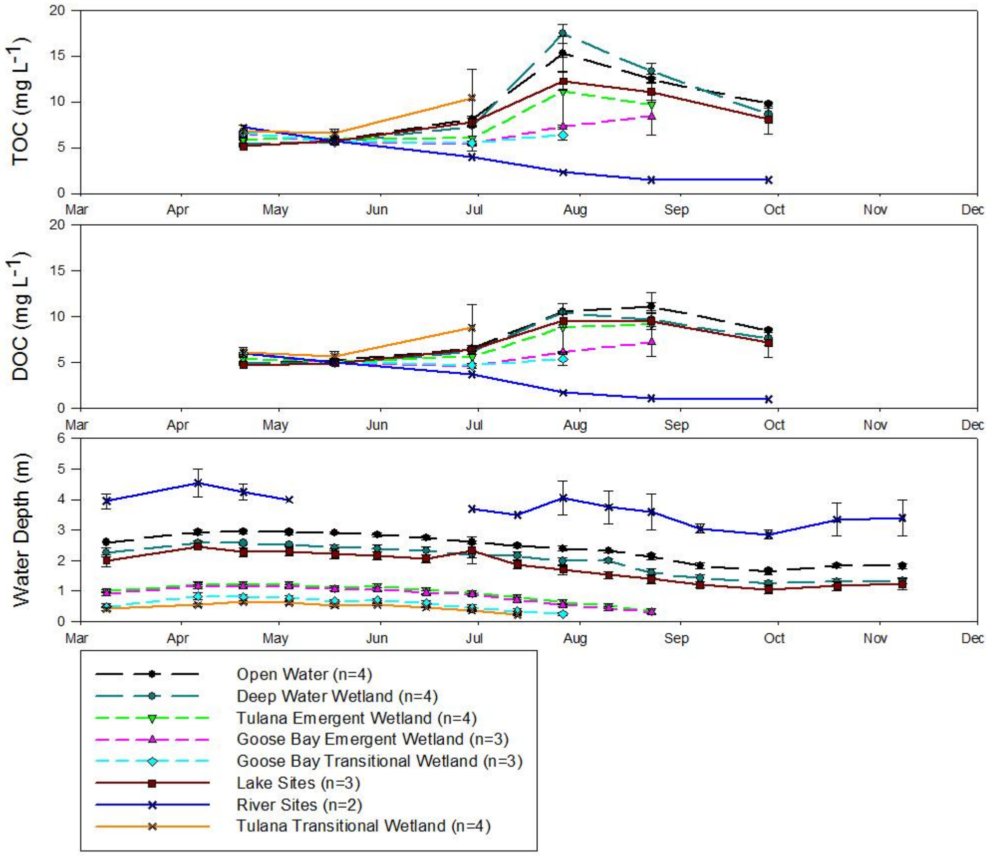


**Figure 4b. Seasonal trends in grab sample constituents and water depth, Williamson River Delta, OR, 2011. Shown are means (± standard error) by location/habitat and sampling event.**

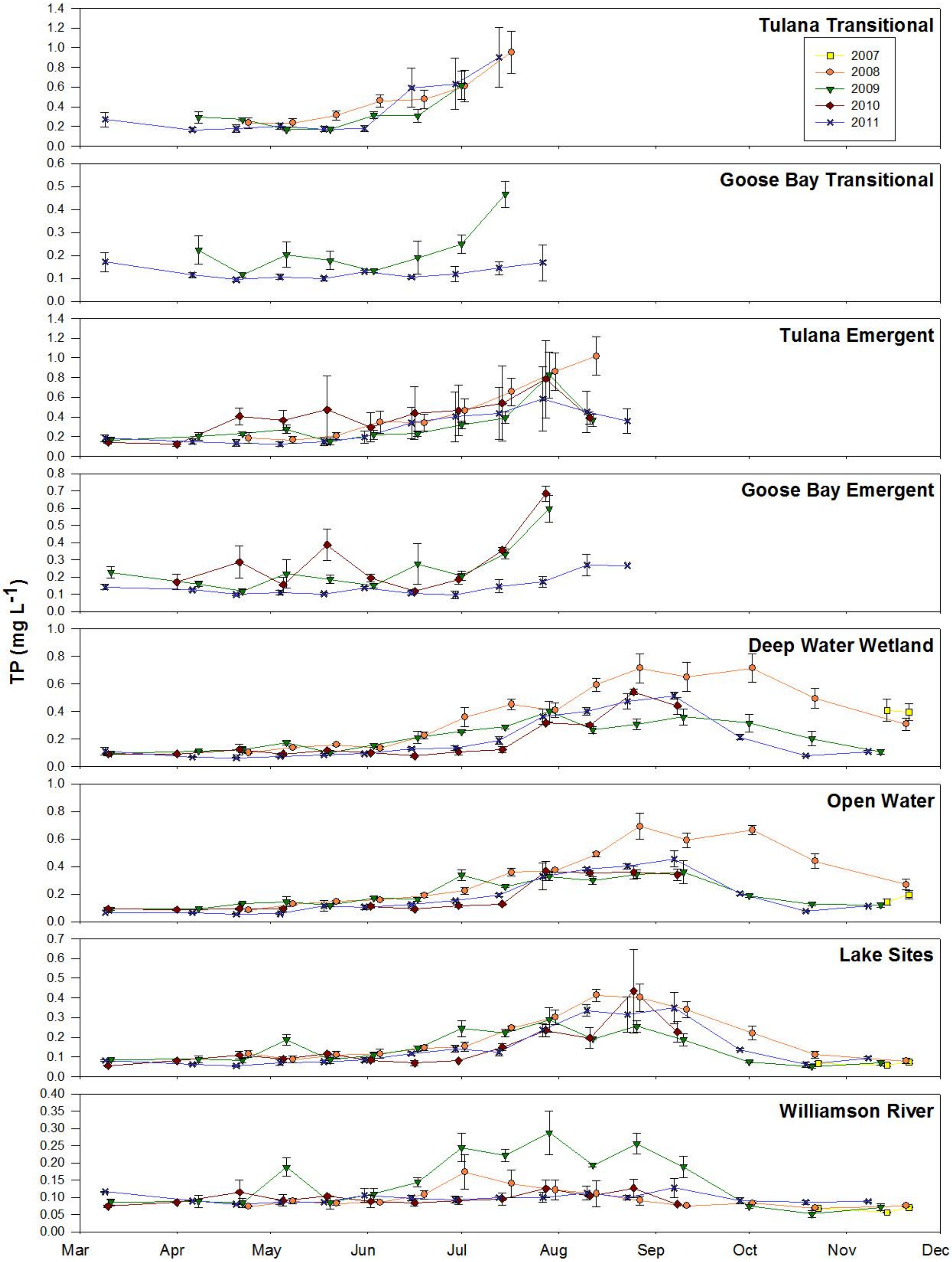


**Figure 5a. Total phosphorus concentrations from 2007–2011 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event.**

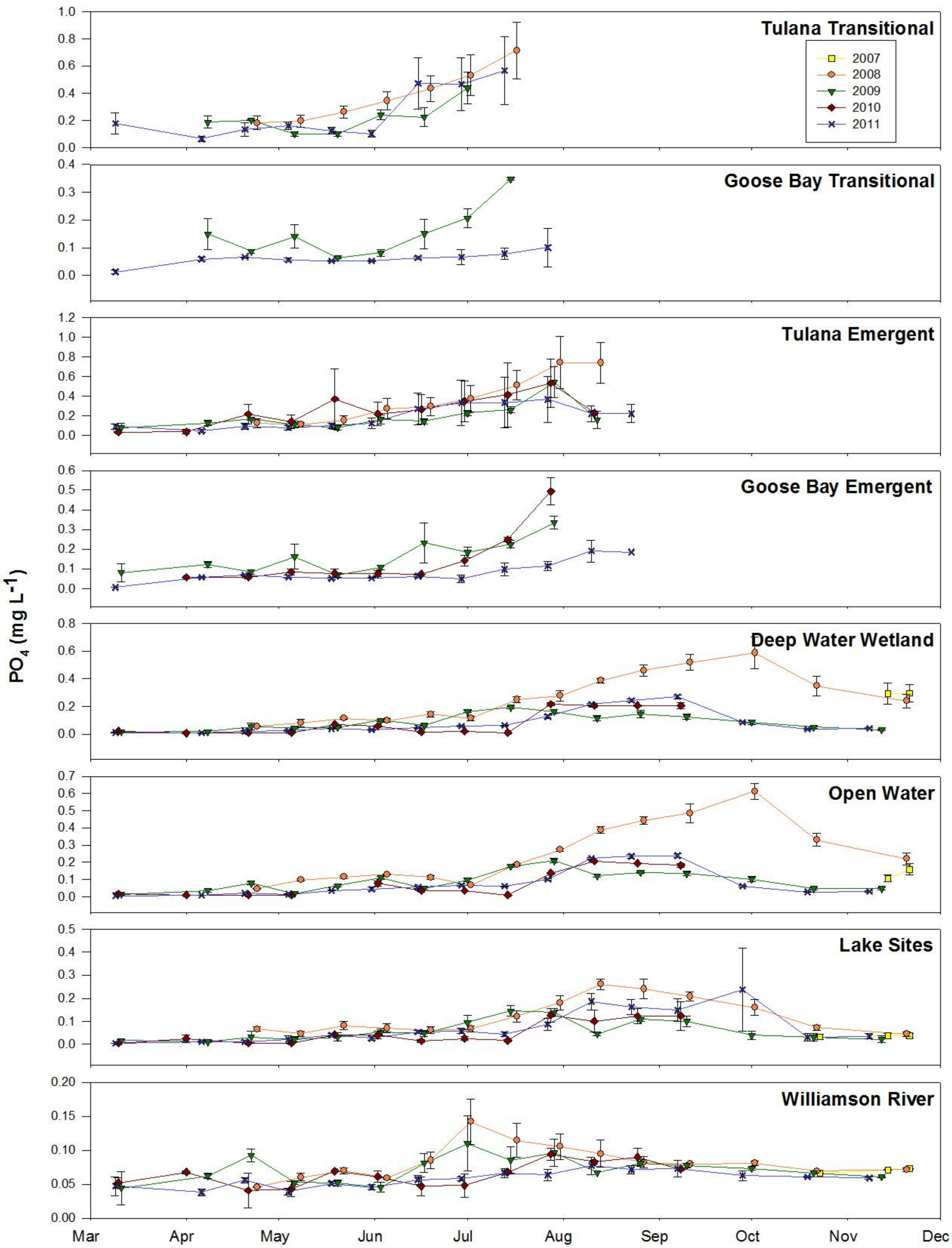


**Figure 5b. Orthophosphate concentrations from 2007–2011 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event.**

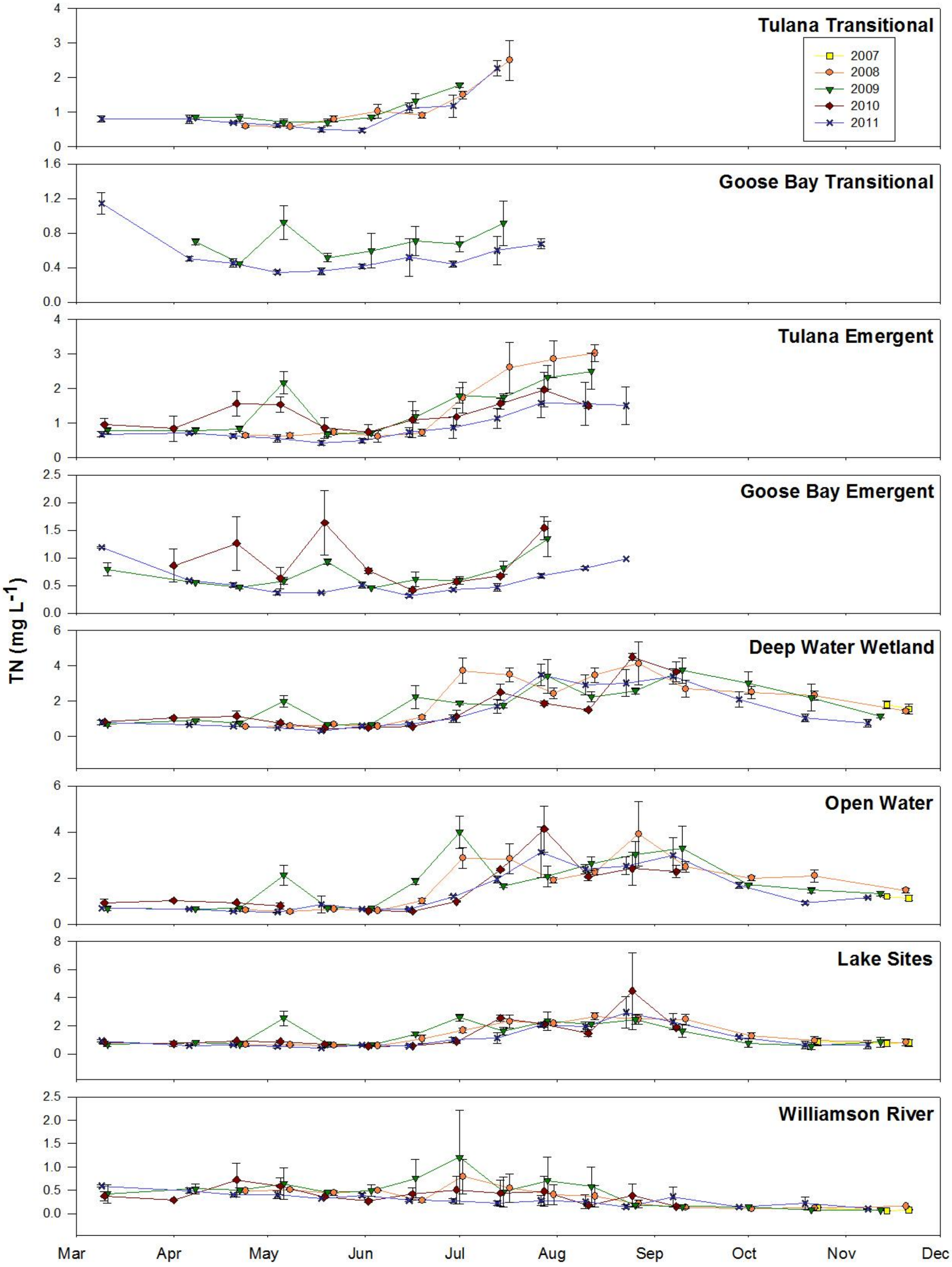


**Figure 5c. Total nitrogen concentrations from 2007–2011 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event.**

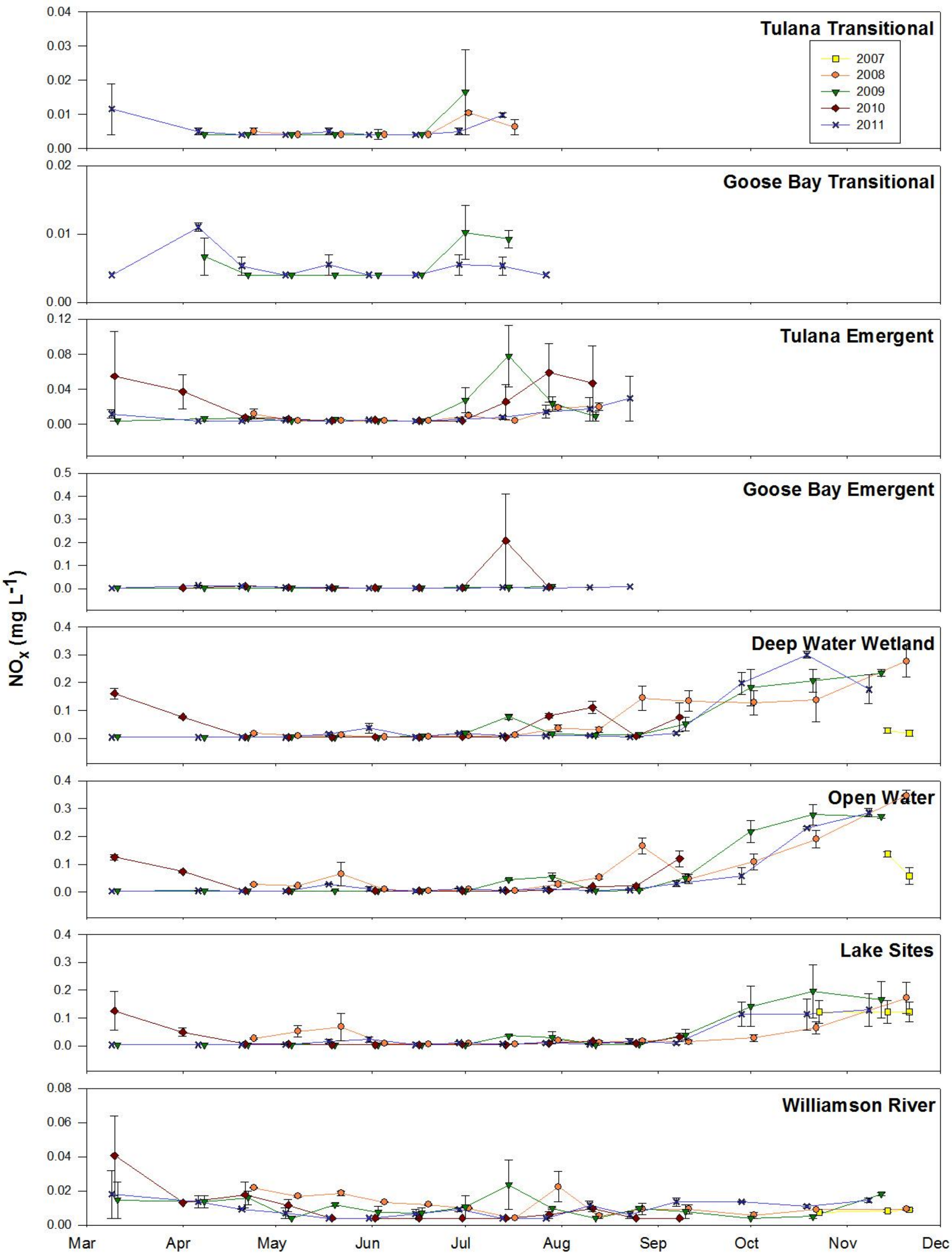


**Figure 5d. The sum of nitrate and nitrite ($NO_X$) concentrations from 2007–2011 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event.**

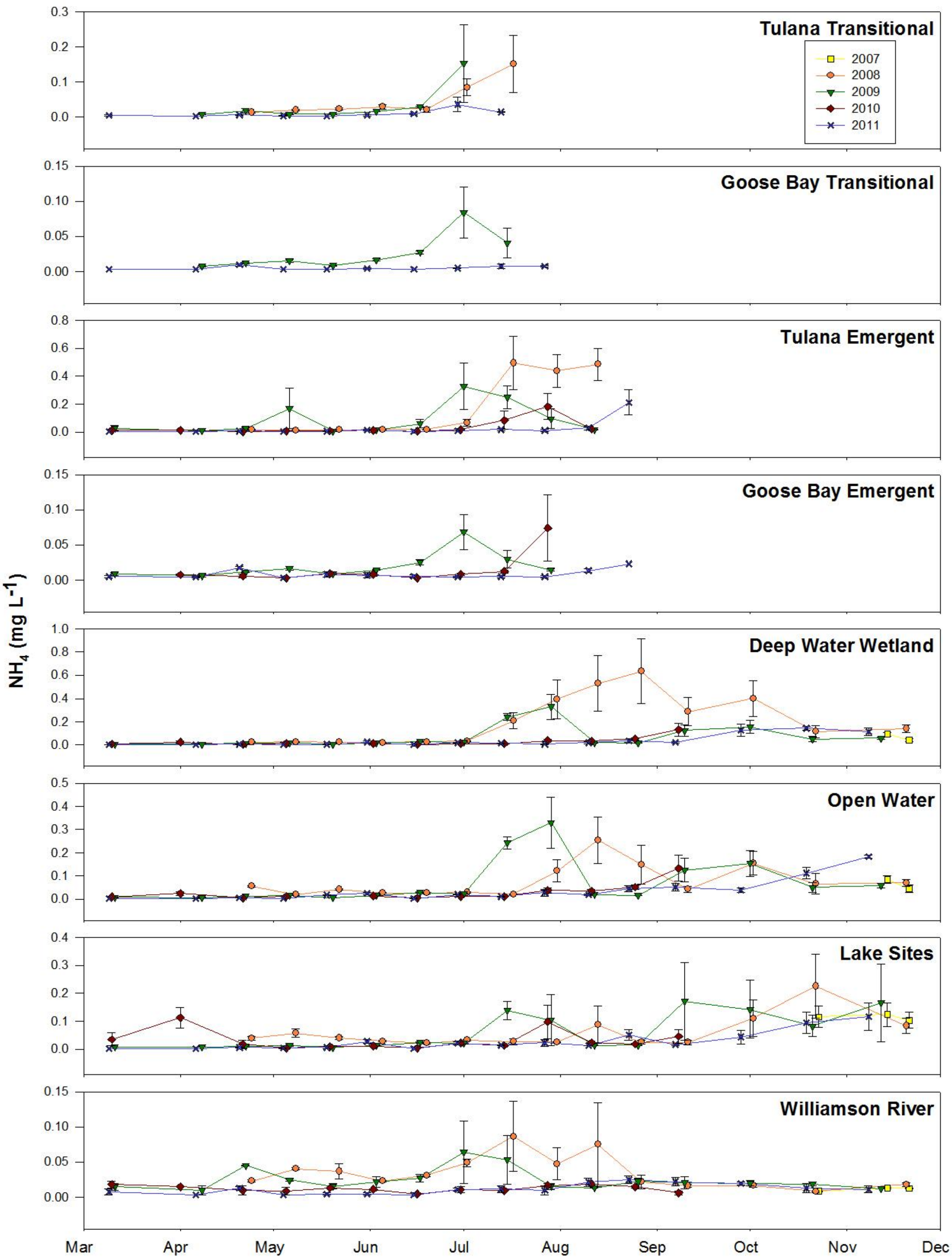


**Figure 5e. Ammonium concentrations from 2007–2011 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event.**

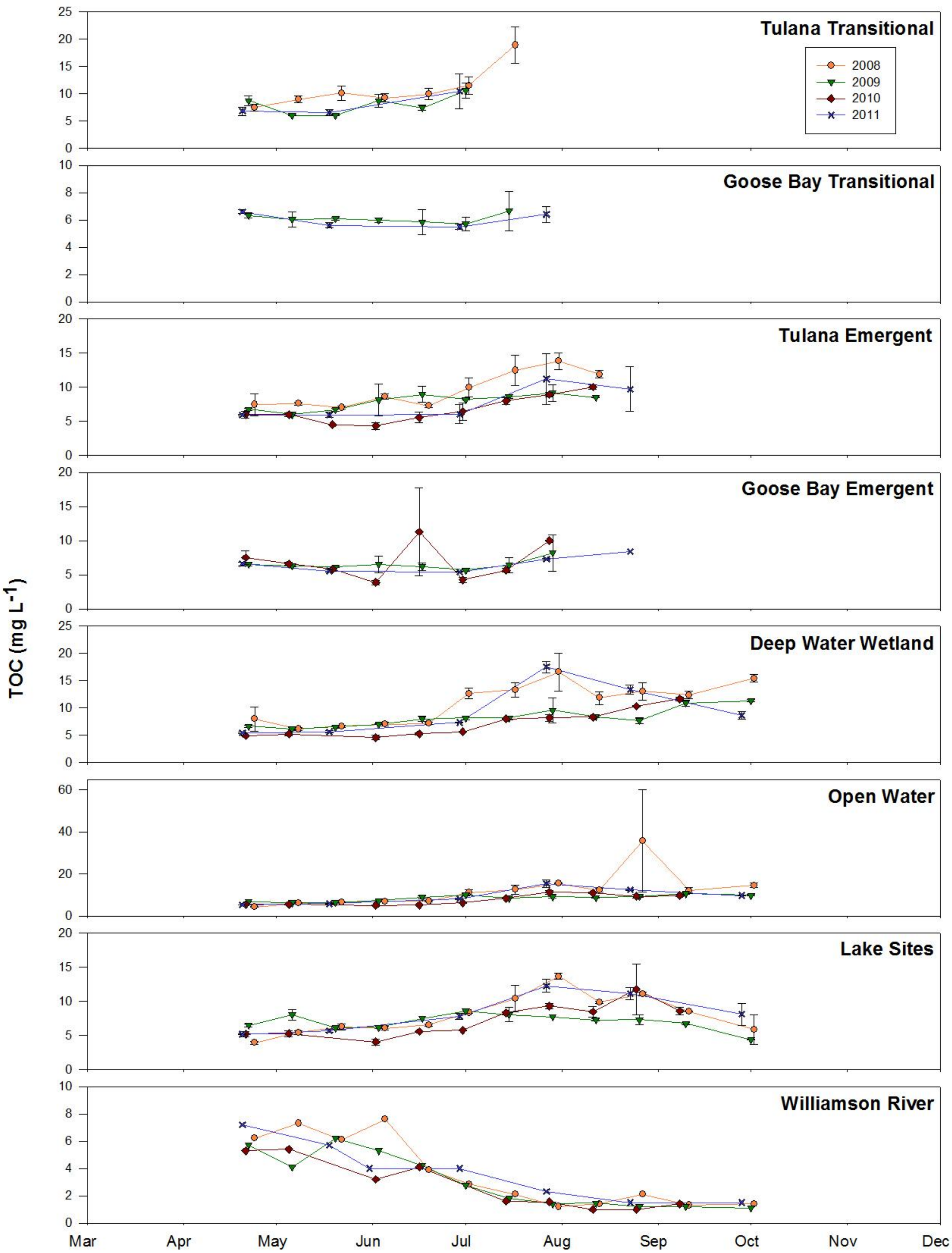


**Figure 5f. Total organic carbon concentrations from 2007–2011 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event.**

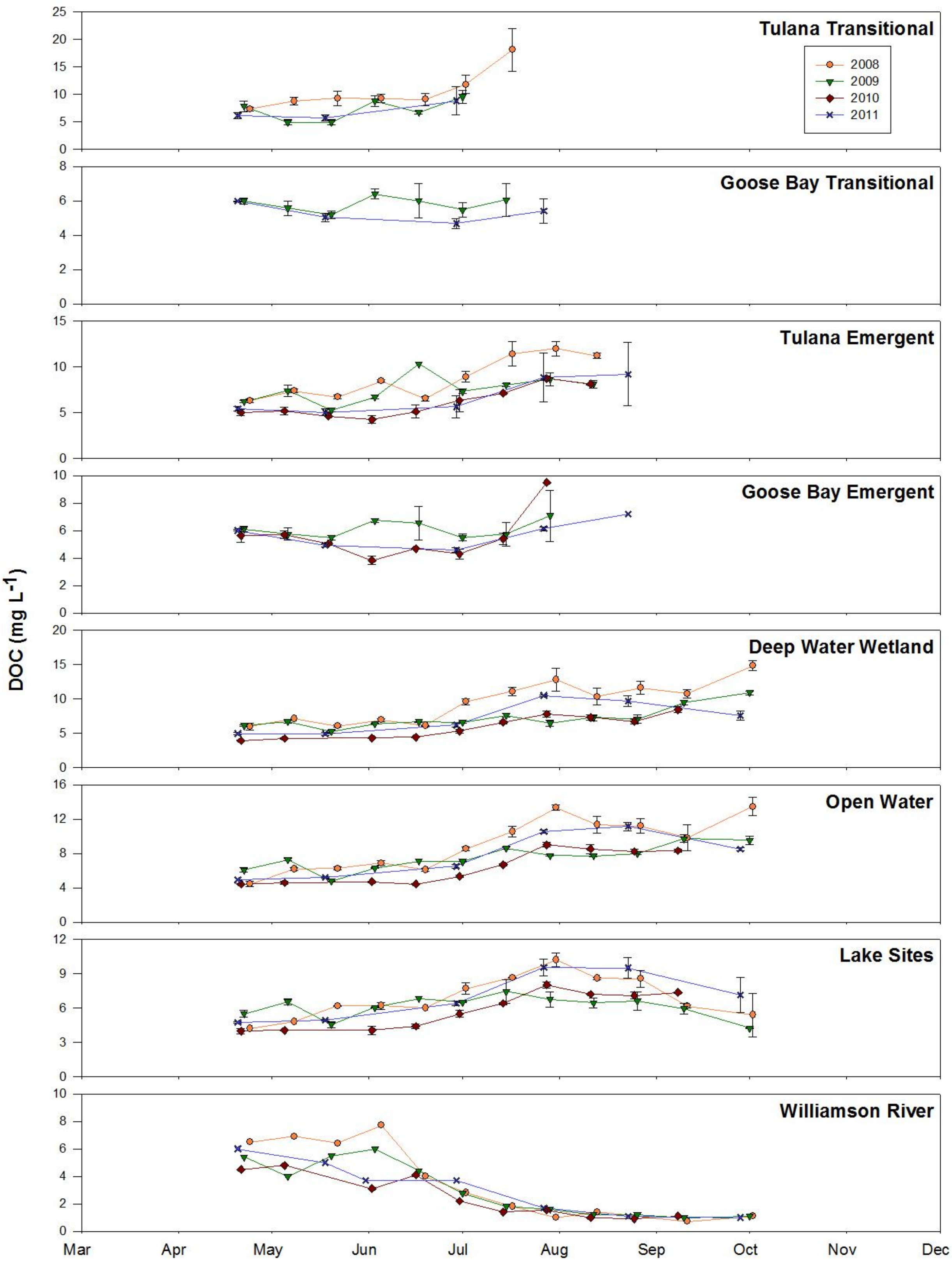


**Figure 5g. Dissolved organic carbon concentrations from 2007–2011 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event.**

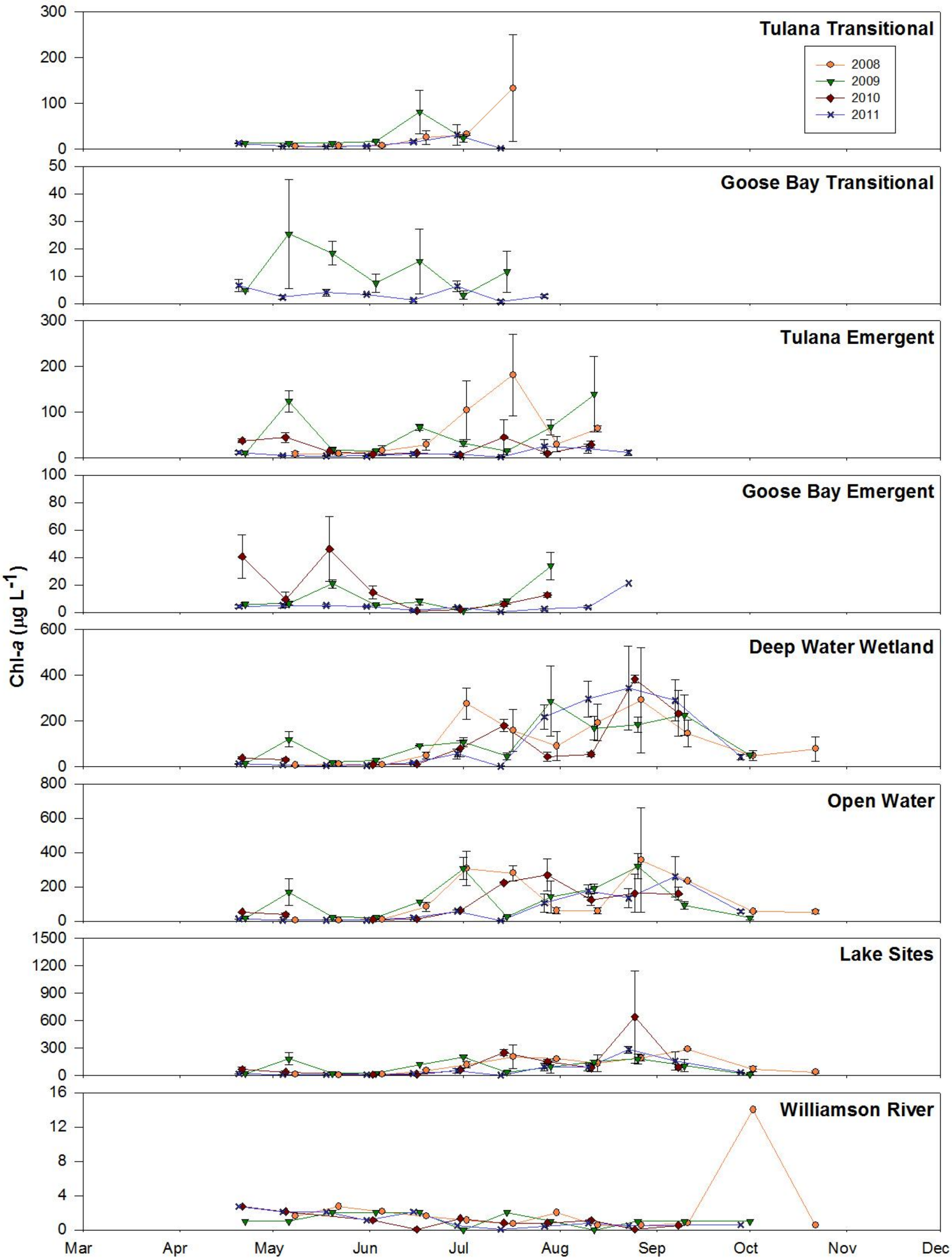


**Figure 5h. Chlorophyll-*a* concentrations from 2007–2011 by habitat type, Williamson River Delta, OR. Shown are means (± standard error) by location/habitat and sampling event.**

## Continuous Monitoring

Seasonal Trends

Water temperatures from March–November ranged from 1.6–30.4 °C among all sites (Table 3). Ambient water temperatures were generally highest in the open water and deep water wetlands, while lowest temperatures were observed in the river sites (Figure 6a,b). During the period May–June, water temperatures between habitat types were similar: average wetland and lake temperatures were 14.3 °C (±0.3), while river sites were slightly lower averaging 13.9 °C. From July–September, the highest average water temperatures were observed in emergent wetlands (22.1 °C). Lake sites, deep water, open water, emergent, and transitional wetlands had similar average temperatures during July–September sampling (20.5 °C ±0.5), while river temperatures remained considerably colder (16.0 °C), respectively. The maximum recorded temperature among all sites was reached on July 6 in Tulana transitional wetlands (30.4 °C). Maximum temperature in the Williamson River was reached on July 7 (20.8 °C) and at the lake sites in early August (25.8–27.4 °C). In the deep water and open water wetlands, the maximum recorded temperatures occurred on July 29 (27.0 °C) and August 3 (26.6 °C). Emergent wetlands reached maximal temperatures on August 23 (27.3 and 29.9 °C), about 2–6 weeks later than in other habitat types.

Dissolved oxygen concentrations were variable throughout the year with concentrations ranging 0.1–23.0 mg $L^{-1}$ in the wetlands, 2.0–27.9 mg $L^{-1}$ in the lakes, and 7.4–13.5 mg $L^{-1}$ in the river (Table 3). Dissolved oxygen concentrations below 1.0 mg $L^{-1}$ were only reached in deep water and Tulana transitional wetlands (Figures 6a,b). Similarly, during the 2010 sampling year DO levels < 1 mg $L^{-1}$ were observed in deep water, Tulana emergent, and South Marsh emergent wetlands. Overall, Tulana transitional wetland had the lowest DO levels, dropping to 0.1 mg $L^{-1}$ in mid-June (Figure 6b). Deep water and open water wetlands, as well as lake sites fluctuated strongly from August through mid-September, and this trend corresponded to the sampling period when chl-*a* levels peaked at these sites (Figures 4a and 6a).

**Table 3. Median, minimum, and maximum values in continuous monitoring variables at continuous monitoring sites, Williamson River Delta, OR, 2011.**

| Location/Habitat | Water Temperature (°C) | | | Specific Conductivity (µS $cm^{-1}$) | | | Dissolved Oxygen (mg $L^{-1}$) | | | pH | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Med | Min | Max | Med | Min | Max | Med | Min | Max | Med | Min | Max |
| Agency Lake (AL27) | 15.7 | 2.8 | 26.3 | 112 | 93 | 238 | 9.8 | 2.0 | 21.1 | 7.8 | 6.6 | 10.2 |
| Upper Klamath Lake West (UKLW25) | 15.5 | 2.0 | 27.4 | 110 | 81 | 154 | 9.8 | 2.9 | 27.9 | 8.0 | 6.5 | 10.0 |
| Upper Klamath Lake East (UKLE24) | 14.9 | 2.2 | 25.8 | 102 | 81 | 154 | 9.8 | 3.5 | 17.6 | 7.8 | 6.6 | 9.9 |
| Williamson River (WR21) | 12.7 | 2.3 | 20.8 | 88 | 68 | 110 | 9.8 | 7.4 | 13.5 | 7.7 | 6.8 | 8.9 |
| Open Water (TLOW17) | 16.1 | 2.9 | 26.6 | 117 | 96 | 183 | 9.8 | 7.4 | 13.5 | 7.8 | 6.6 | 10.3 |
| Deep Water Wetland (TLDW13) | 16.0 | 2.4 | 27.0 | 115 | 76 | 187 | 9.3 | 0.5 | 23.0 | 7.9 | 6.5 | 10.5 |
| Tulana Emergent Wetland (TLEM9) | 15.3 | 2.2 | 27.3 | 92 | 69 | 123 | 9.6 | 6.2 | 16.4 | 7.7 | 7.0 | 9.7 |
| Transitional Wetland (TLTR5) | 12.0 | 2.2 | 30.4 | 109 | 71 | 177 | 10.0 | 0.1 | 21.3 | 7.9 | 6.5 | 10.3 |
| Goose Bay Emergent Wetland (GBEM4) | 15.2 | 1.6 | 29.9 | 89 | 69 | 150 | 10.0 | 1.4 | 16.8 | 7.7 | 7.0 | 9.9 |

Among all sites, pH ranged from 6.5–10.5 throughout the year, with values reaching above 10.0 at all sites except in Upper Klamath Lake east, Williamson River, Tulana and Goose Bay emergent wetlands (Table 3). Peak pH levels were observed from early June through mid-September at all sites, except the Williamson River which remained relatively consistent throughout the year. The increase in pH across habitat types preceded seasonal peaks in chl-*a* and DO concentrations (Figures 5h and 6b).

Specific conductance values ranged from 69–187 µS $cm^{-1}$ in the wetlands, 81–238 µS $cm^{-1}$ in the lakes, and 68–110 µS $cm^{-1}$ in the river (Table 3). The lowest range in values occurred in the river, while the highest values occurred in Agency Lake from April-September, followed by open water and deep water wetlands having the highest conductance values from October-November (Figure 6a,b). Tulana transitional and Goose Bay emergent wetlands also peaked in early July and late August before the sites were dropped due to receding water levels.

<u>High Stress Threshold Conditions for Endangered Suckers</u>

Water quality was examined in relation to conditions of water temperature, DO, and pH potentially threatening to the health of endangered Lost River and shortnose suckers in Upper Klamath Lake. Based on Loftus (2001), conditions in which high stress thresholds for suckers are reached include water temperature>28°C, DO<4 mg/L, and pH>9.7. The seasonal timing and duration, location, and severity of these conditions in the wetlands and near-shore lakes are described.

Threshold exceedances did not occur for any of the three parameters in the Williamson River or Tulana emergent wetlands. Temperature exceedances occurred only in the Goose Bay emergent and Tulana transitional wetlands, reaching up to 17% and 21% of the day, respectively, in early July and late August (Figure 7).

Exceedances of the pH threshold were observed in all lake and wetland habitats except in Tulana emergent wetlands. However, conditions were not severe (prolonged during the day) nor did they persist through the season in any of the lake sites or in Goose Bay emergent and Tulana transitional wetlands (Figure 7). Conditions were the most severe at Tulana open water and deep water wetlands, where conditions of pH>9.7 peaked at 100% and 80% of the day in late July and August. Lake sites experienced smaller lengths of time when pH surpassed threshold levels, particularly Upper Klamath Lake west and east, located near the river mouth. These sites only reached exceedances of 15% and 17% of the day in August.

Exceedances of the DO threshold were observed in all lake and wetland sites, except Tulana emergent wetlands. Similar to pH conditions, DO threshold exceedances were neither severe nor persistent through the season in lake sites, Goose Bay emergent, or Tulana transitional wetland. Conditions were most severe at open water and deep water wetland sites during August and September, where conditions of low DO (<4 mg $L^{-1}$) reached 96% and 100% of the day (Figure 7). Low DO conditions persisted the longest in deep water wetlands from early August through late September, relative to other habitat types. A very different trend was observed in lake sites, where only one peak was observed in mid-September and the percent of time where DO exceedances occurred decreased with proximity to the Williamson River inflow. For example, Agency Lake exceedances reached 60% of the day, whereas Upper Klamath Lake west and east (closest to the river mouth) only reached 25% and 5% of the day, respectively. Goose Bay emergent and Tulana transitional wetlands had moderate and early peaks in DO exceedances before monitoring was discontinued at these sites, 30% of the day in late August (Goose Bay emergent) and 67% of the day in mid-July (Tulana transitional).

Year comparisons of high stress conditions for endangered suckers revealed a noticeable reduction in the amount of total hours per sampling season (March–November) where threshold exceedances were observed. For example, in 2008 21% of the total hours exceeded critical DO levels, compared to 16% in 2009, 15% in 2010, and 6% in 2011. Similarly, critical pH levels were exceeded 19% of the time in 2008, 15% in 2009, 9% in 2010, and 5% in 2011. In previous years (2008-2010), Agency Lake has had pH levels most threatening to suckers; however, in 2011 Agency and other lake sites had moderate pH exceedances, while open water wetlands were most threatening to suckers. Dissolved oxygen was severely low more frequently in Tulana transitional wetlands (2008-2009; note: in 2010 transitional wetlands were not sampled because water levels were too low, South Marsh wetlands were sampled instead, which had the most threatening DO levels in 2010). In 2011, deep water wetlands had the greatest proportion of time where DO thresholds were surpassed (6% of the time) and Tulana transitional wetlands exceeded DO thresholds 5% of the time. Temperature exceedances were relatively low between all sampling years with no inter-annual trend.

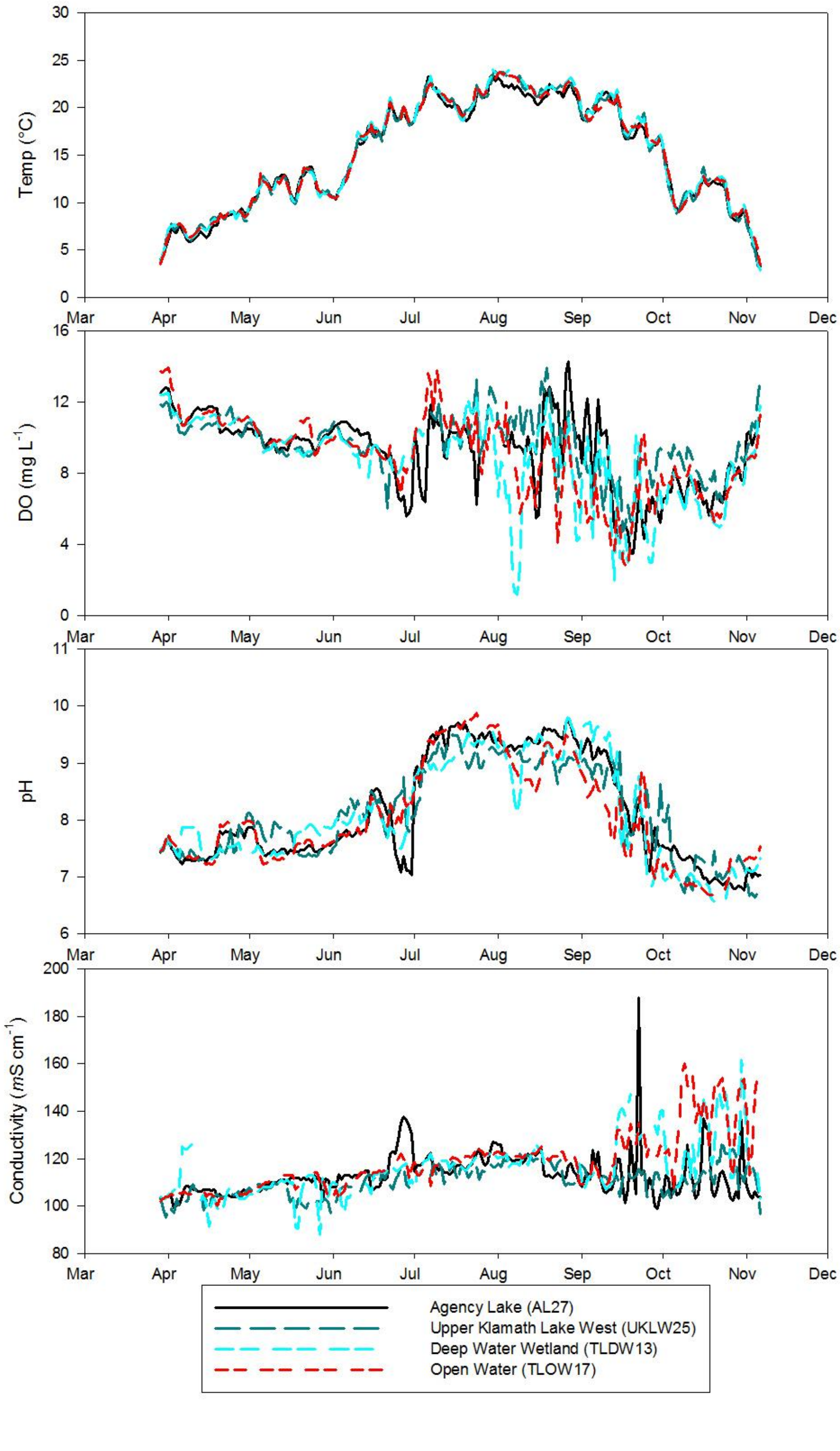


**Figure 6a. Seasonal trends in continuous monitoring variables at lake and wetland sites, Williamson River Delta, OR, 2011. Shown as daily median by location/habitat and sampling event.**

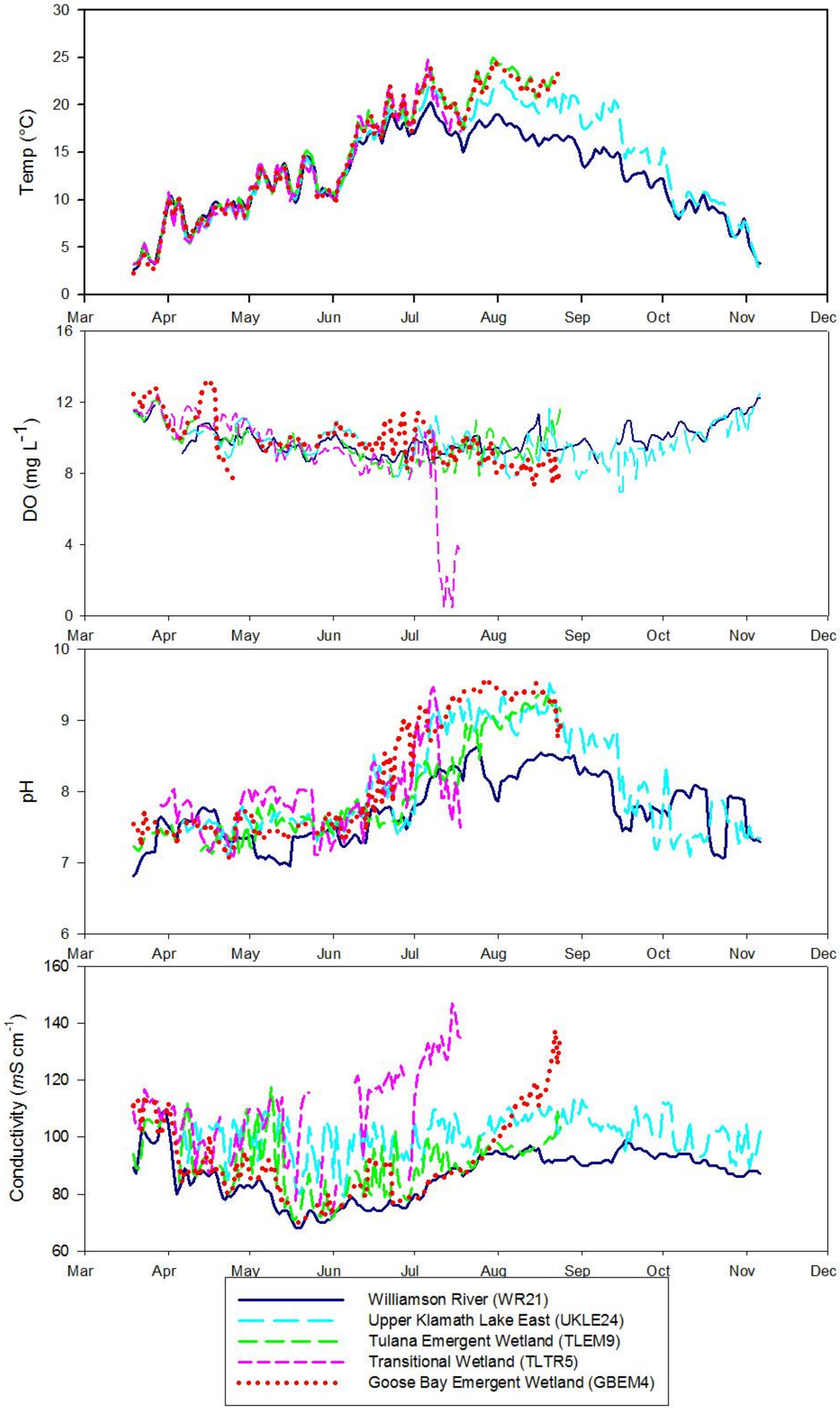


**Figure 6b. Seasonal trends in continuous monitoring variables at lake, wetland, and river sites, Williamson River Delta, OR, 2011. Shown as daily median by location/habitat and sampling event.**

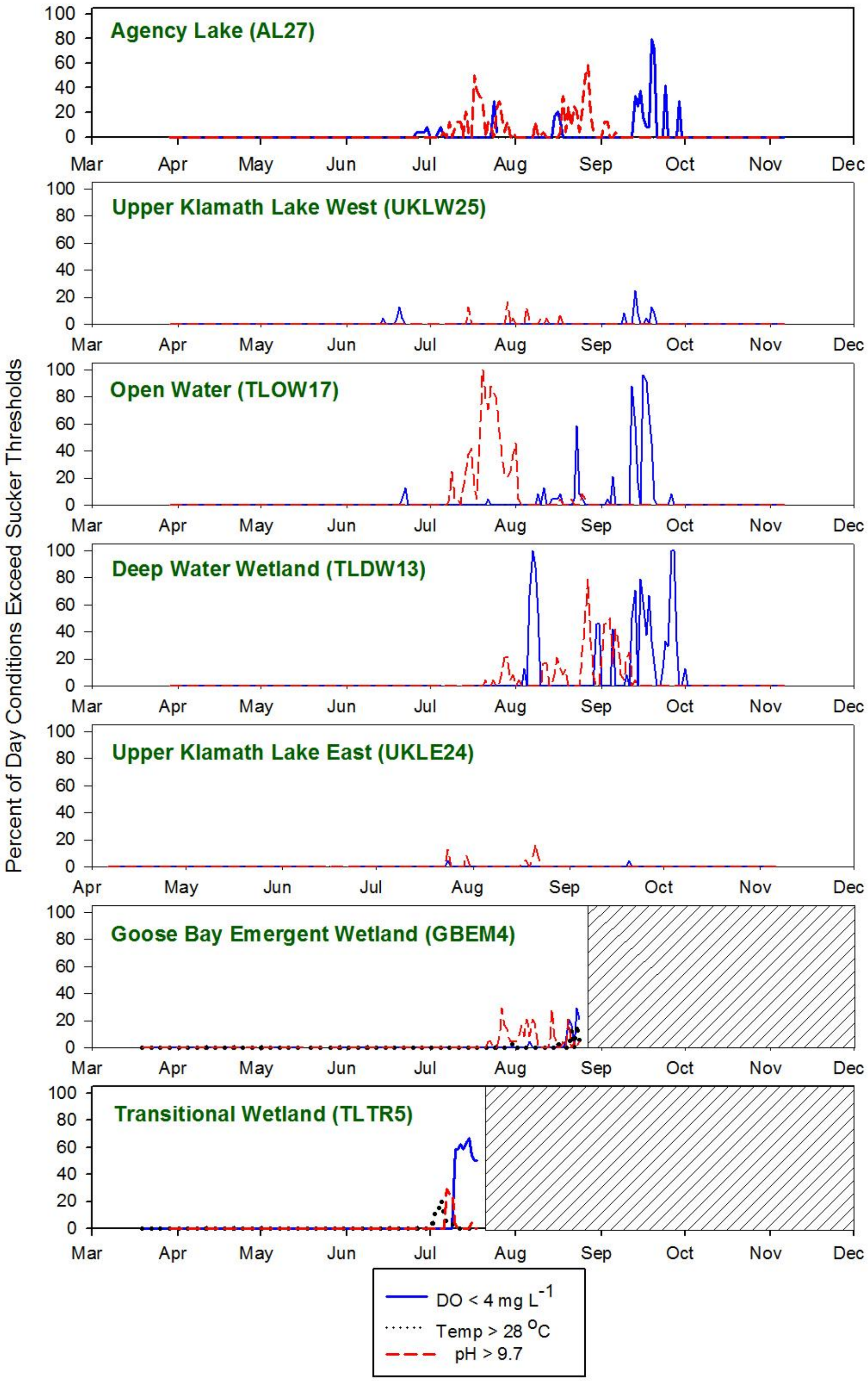


**Figure 7. Location, timing, and duration of water quality conditions potentially harmful to Lost River and shortnose suckers (Loftus 2001), Williamson River Delta, OR, 2011. Hatched areas indicate discontinuation of monitoring.**

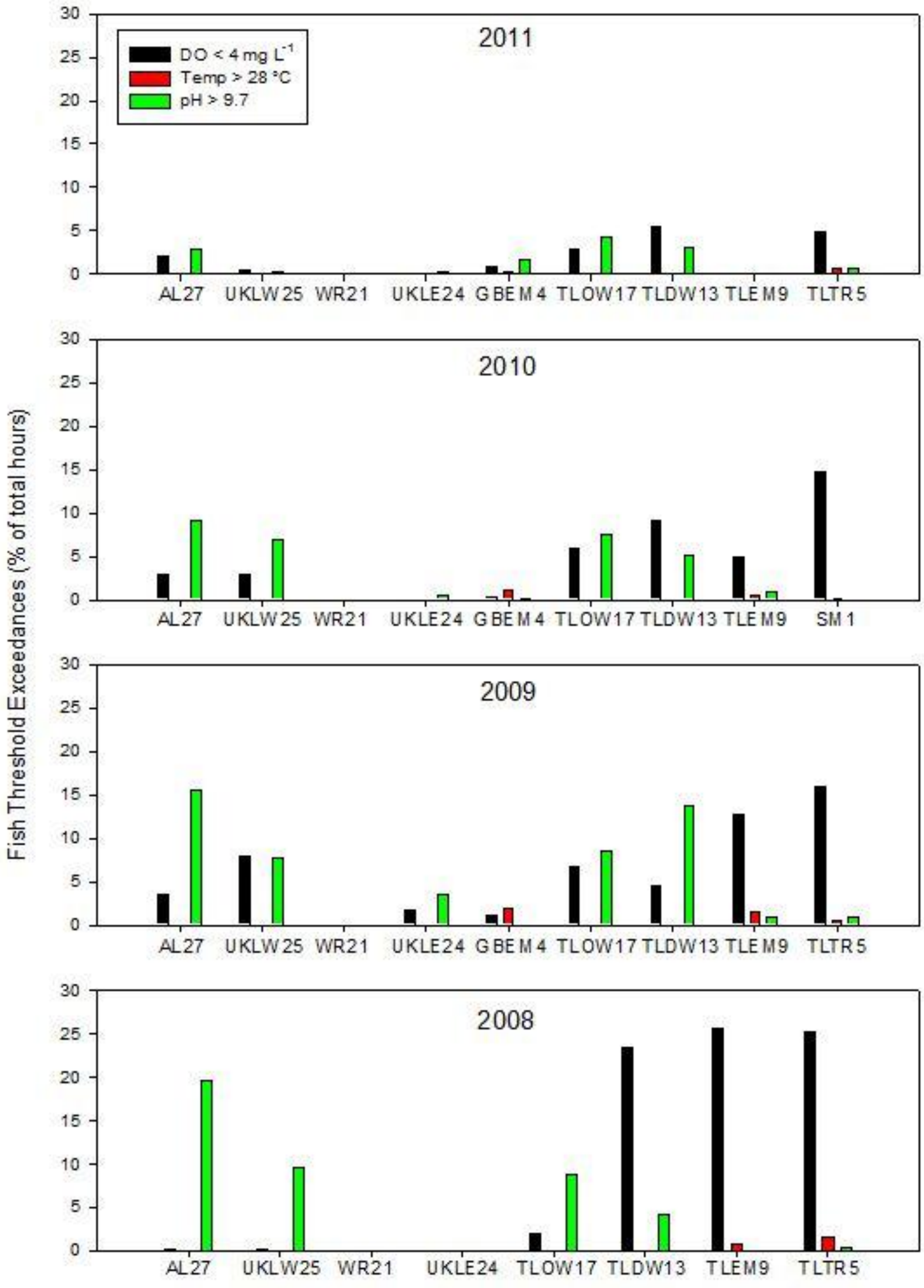


**Figure 8. Comparison of the percent of total hours between March and November where conditions exceeded high stress threshold levels for suckers. Data is representative of different habitat types for four post-restoration years at the Williamson River Delta, OR.**

## DISCUSSION & CONCLUSION

In general, trends in nutrient and chl-*a* concentrations in the permanently flooded wetlands exhibited seasonal variation typical of bloom and crash cycles of *Alphanizemenon flos-aquae* (AFA), while trends in the shallow emergent wetlands exhibited seasonal and spatial variation that may be associated with various factors not discussed in this report (i.e., water depth, vegetation, soils, hydrology). Particularly in the permanently flooded wetlands, algal dynamics (i.e., primary productivity and algal biomass as represented by chl-*a*) appeared to be a main factor exerting control on seasonal trends in water chemistry including DO and pH—trends typical of Upper Klamath and Agency Lakes (Lindenberg et al. 2008). Consequently, DO and pH values in the permanently flooded wetlands (deep water and open water wetlands) reached conditions potentially stressful to the health of endangered suckers during the summer and fall months, exceeding stressful conditions observed in lake sites, transitionally flooded, and emergent wetlands. When compared to previous post-restoration sampling years, conditions in 2011 had the lowest proportion of time when critical pH and DO thresholds were exceeded across habitat types. A gradual decrease has been observed from 2008–2011. Most notably, DO concentrations reached less than critical levels 21% of total hours in 2008; during the same sampling period in 2011 it had decreased 6% of the time. Similarly, pH thresholds were exceeded 19% of the time in 2008, compared to 5% in 2011. No critical thresholds were reached in Tulana emergent wetlands during 2011, unlike earlier sampling years where temperature and DO exceedances have always been observed. The exact cause may be due in part to multiple factors. Williamson River mean daily discharge was higher in 2011 compared to the past 93 year mean (Figure 3); this increase of freshwater inflow may have subsequently reduced sucker exceedances observed near river mouth sites, such as Upper Klamath Lake east. Alternately, re-connectivity of Delta hydrology, reduction in agricultural and nutrient return flow, as well as N and P nutrient cycling by wetlands and benthic influences or some combination of these and other factors may all impact surface water quality,.

Compared to previous years of monitoring, seasonal trends and ranges in N and P concentrations in 2011 were generally lower than 2007-2009 and only slightly lower or in a similar range as 2010 concentrations. It appears that the large, benthic pulse of nutrients associated with initially re-flooding the wetlands has diminished since 2007 and 2008 (Aldous et al. 2007, Wong et al. 2010). However, data collected by the USGS from pore-water samplers deployed at sites representing a small area of the wetlands have shown that the wetlands continued to exhibit a positive benthic flux of phosphorus in 2010 (J. Kuwabara, USGS, personal communication). Quantifying an accurate load from the wetlands as a whole since 2008 may be difficult or impossible because of the hydrologic connectivity and spatial complexity of the wetlands. Despite this, it is reasonable to speculate based on data collected from the past 4 years of monitoring that the wetlands are continuing to transition toward a more equilibrium state with the surrounding lakes and river in terms of surface water chemistry.

This report summarizes results from the fourth full year of post-restoration water quality monitoring at the Williamson River Delta. A more comprehensive report will be presented upon project completion in winter 2012.

## ACKNOWLEDGMENTS

The Oregon Watershed Enhancement Board (grant agreement #209-4040)and the National Fish and Wildlife Foundation (agreement # 2009-0075-000) graciously provided funding and support for this monitoring project. Many individuals contributed to the planning and development of this monitoring project including Mark Stern, Matt Barry, Jason Cameron, Mary Lindenberg, and Tamara Wood. We gratefully acknowledge Allison Aldous and Nathan Rudd at The Nature Conservancy for providing thoughtful guidance and analytical support for this project; Kris Fischer and Ben Harris at the Klamath Tribes' Sprague River Water Quality Laboratory for providing laboratory space and support; Jessica Asbill, Mariah Tilman, and JR Schanzenbacher at the US Bureau of Reclamation for providing technical support for YSI instruments; and Melody Warner, Joanna Long, Alix Lee, and Kellen Watson for assistance with field work.

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# APPENDICES

**Appendix A. Quality assurance results for nutrient and chlorophyll-*a* samples collected in 2011.**

| Split Samples | Number of Samples | | % Total Samples | Difference between splits | |
|---|---|---|---|---|---|
| **Analyte** | **Splits** | **Total** | | **Median (mg L$^{-1}$)** | **Median (Relative Percent Difference)** |
| Total Phosphorus | 36 | 348 | 10% | 0.128 | 0.47 |
| Orthophoshate | 36 | 348 | 10% | 0.059 | 0 |
| Total Nitrogen | 36 | 348 | 10% | 0.697 | 2.15 |
| Ammonia | 36 | 348 | 10% | 0.009 | 0 |
| Nitrate + Nitrite | 36 | 348 | 10% | 0.008 | 0 |
| Chlorophyll *a* | 24 | 208 | 11% | 0.006 | 0 |
| Total Organic Carbon | 12 | 102 | 12% | 5.500 | 0.90 |
| Dissolved Organic Carbon | 12 | 102 | 12% | 6.150 | 0.50 |

| Duplicate Samples | Number of Samples | | % Total Samples | Difference between duplicates | |
|---|---|---|---|---|---|
| **Analyte** | **Duplicates** | **Total** | | **Median (mg L$^{-1}$)** | **Median (Relative Percent Difference)** |
| Total Phosphorus | 16 | 348 | 5% | 0.095 | 0 |
| Orthophoshate | 16 | 348 | 5% | 0.051 | 0.59 |
| Total Nitrogen | 16 | 348 | 5% | 0.541 | 1.10 |
| Ammonia | 16 | 348 | 5% | 0.010 | 0 |
| Nitrate + Nitrite | 16 | 348 | 5% | 0.009 | 0 |

| Lab Blanks | Number of Samples | | % Total Samples | Minimum Reporting Level (mg L$^{-1}$) | Value of blank samples greater than reporting limit |
|---|---|---|---|---|---|
| **Analyte** | **Blank** | **Total** | | | **Maximum (mg L$^{-1}$)** |
| Total Phosphorus | 2 | 348 | 1% | 0.036 | NA* |
| Orthophoshate-P | 2 | 348 | 1% | 0.006 | NA |
| Total Nitrogen | 2 | 348 | 1% | 0.06 | NA |
| Ammonia | 2 | 348 | 1% | 0.012 | NA |
| Nitrate + Nitrite | 2 | 348 | 1% | 0.016 | NA |
| Chloropyhll a | 1 | 208 | 0.5% | 0.0001 | NA |

*NA=Not applicable, values below RL

**Appendix A, continued.**

| **Equipment Blanks** | **Number of Samples** | | **% Total Samples** | **Minimum Reporting Level (mg $L^{-1}$)** | **Value of blank samples greater than reporting limit** |
|---|---|---|---|---|---|
| **Analyte** | **Blank** | **Total** | | | **Maximum (mg $L^{-1}$)** |
| Total Phosphorus | 1 | 348 | 0.3% | 0.036 | NA* |
| Orthophoshate-P | 1 | 348 | 0.3% | 0.006 | NA |
| Total Nitrogen | 1 | 348 | 0.3% | 0.060 | NA |
| Ammonia | 1 | 348 | 0.3% | 0.012 | NA |
| Nitrate + Nitrite | 1 | 348 | 0.3% | 0.016 | NA |

*NA=not applicable, values below RL

| **Rinsate Blanks** | **Number of Samples** | | **% Total Samples** | **Minimum Reporting Level (mg $L^{-1}$)** | **Value of blank samples greater than reporting limit** |
|---|---|---|---|---|---|
| **Analyte** | **Blank** | **Total** | | | **Maximum (mg $L^{-1}$)** |
| Total Phosphorus | 2 | 348 | 1% | 0.036 | NA* |
| Orthophoshate-P | 2 | 348 | 1% | 0.006 | NA |
| Total Nitrogen | 2 | 348 | 1% | 0.060 | NA |
| Ammonia | 2 | 348 | 1% | 0.012 | NA |
| Nitrate + Nitrite | 2 | 348 | 1% | 0.016 | NA |

*NA=not applicable, values below RL

| **Spike Samples** | **Number of Samples** | | **% Total Samples** | **Recovery < 80% (% Spike Samples)** | **Recovery>120% (% Spike Samples)** |
|---|---|---|---|---|---|
| **Analyte** | **Spikes** | **Total** | | | |
| Total Phosphorus | 37 | 348 | 11% | 51% | 5% |
| Orthophoshate | 37 | 348 | 11% | 24% | 16% |
| Total Nitrogen | 37 | 348 | 11% | 51% | 19% |
| Ammonia | 37 | 348 | 11% | 3% | 0% |
| Nitrate + Nitrite | 37 | 348 | 11% | 0% | 0% |

**Appendix B. Detection and reporting limits for grab sample constituents, standard method number, and laboratory conducting the analysis.**

| Constituents | Detection Limit (mg/L) | Reporting Limit (mg/L) | Standard Method | Laboratory |
|---|---|---|---|---|
| Total Phosphorus | 0.018 | 0.036 | SM4500-P H | Sprague River Water Quality Laboratory, OR |
| Orthophosphate | 0.003 | 0.006 | SM4500- PF | |
| Ammonia | 0.006 | 0.012 | MD Krom methods | |
| Nitrate + Nitrite | 0.008 | 0.016 | Enzymatic NO3; SM4500-NO2 | |
| Total Nitrogen | 0.03 | 0.06 | Enzymatic NO3 | |
| Total Organic Carbon | 0.2 | 0.5 | SM 5310 | Basic Laboratory, CA |
| Dissolved Organic Carbon | 0.2 | 0.5 | SM5310C | |
| Chlorophyll-a | 0.0001 | NA | SM10200H | Aquatic Research, WA |

**Appendix C. Quality assurance criteria for continuous monitoring data. Level A criteria represent the highest quality data as defined in TNC's Quality Assurance Project Plan. Level B criteria represent data outside Level A criteria, but deemed acceptable for statistical analysis. Level C criteria represent data deemed unacceptable and omitted prior to analysis.**

| Data Quality Level | Quality Assurance Plan & Action Steps | Water Temperature | pH | Dissolved Oxygen Concentration | Specific Conductance |
|---|---|---|---|---|---|
| A | QA Criteria Met: Data Accepted | ± 0.5°C | ± 0.2 | ± 0.3 mg/L | ± 7% of std value |
| B | QA Criteria Not Met: Data Accepted; QA Reported | ± 2.0°C | ± 0.5 | ± 1.0 mg/L | ± 10% of std value |
| C | QA Criteria Not Met: Data Omitted, QA Reported | > ± 2.0°C | > ± 0.5 | > ± 1.0 mg/L | > ± 10% of std value |

**Appendix D. Quality assurance results for continuous monitoring in 2011. Data meeting Level A quality assurance criteria are not shown. 'No Data' indicates that no data were recorded for all four parameters due to equipment or other problems.**

| Continuous Monitor Site | Data Quality Level | Parameter | Dates | Continuous Monitor Site | Data Quality Level | Parameter | Dates |
|---|---|---|---|---|---|---|---|
| AL27 | B | DO | 03/28/11 - 04/05/11 | WR21 | B | DO | 05/03/11 - 05/17/11 |
| AL27 | B | DO | 04/11/11 - 04/19/11 | WR21 | B | DO | 05/24/11 - 06/03/11 |
| AL27 | B | DO | 05/03/11 - 05/10/11 | WR21 | B | DO | 06/03/11 - 06/14/11 |
| AL27 | B | DO | 05/17/11 - 05/24/11 | WR21 | B | DO | 06/ 14/11 - 06/23/11 |
| AL27 | B | DO | 06/03/11 - 06/14/11 | WR21 | B | DO | 06/26/11 - 07/06/11 |
| AL27 | B | DO | 06/14/11 - 06/23/11 | WR21 | B | DO | 07/12/11 - 08/17/11 |
| AL27 | B | pH, DO | 07/06/11 - 07/12/11 | WR21 | B | DO | 08/25/11 - 08/30/11 |
| AL27 | C | DO | 07/26/11 - 08/02/11 | WR21 | C | DO | 09/08/11 - 09/13/11 |
| AL27 | B | DO | 08/09/11 - 08/17/11 | WR21 | B | DO | 09/13/11 - 09/20/11 |
| AL27 | B | DO | 08/24/11 - 08/30/11 | WR21 | B | pH, DO | 10/18/11 - 10/25/11 |
| AL27 | B | DO | 09/20/11 - 09/27/11 | TLOW17 | B | DO | 03/28/11 - 04/05/11 |
| AL27 | B | DO | 10/18/11 - 10/25/11 | TLOW17 | B | DO | 04/12/11 - 04/19/11 |
| UKLW25 | B | DO | 04/05/11 - 04/12/11 | TLOW17 | B | DO | 04/26/11 - 05/02/11 |
| UKLW25 | B | DO | 04/19/11 - 40/26/11 | TLOW17 | B | DO | 05/10/11 - 05/17/11 |
| UKLW25 | B | DO | 05/03/11 - 05/10/11 | TLOW17 | B | DO | 05/17/11 - 05/24/11 |
| UKLW25 | B | DO | 05/24/11 - 06/03/11 | TLOW17 | B | pH | 06/03/11 - 06/14/11 |
| UKLW25 | B | DO | 06/14/11 - 06/23/11 | TLOW17 | B | DO | 06/23/11 - 06/28/11 |
| UKLW25 | C | DO | 06/23/11 - 06/28/11 | TLOW17 | B | DO | 07/06/11 - 07/12/11 |
| UKLW25 | C | DO | 06/28/11 - 07/06/11 | TLOW17 | B | DO | 07/26/11 - 08/02/11 |
| UKLW25 | B | DO | 08/02/11 - 08/09/11 | TLOW17 | B | DO | 08/09/11 - 08/17/11 |
| UKLW25 | B | DO | 08/17/11 - 08/30/11 | TLOW17 | B | DO | 08/25/11 - 08/30/11 |
| UKLW25 | B | DO | 09/20/11 - 10/04-11 | TLOW17 | B | DO | 09/08/11 - 09/13/11 |
| UKLW25 | B | DO | 10/13/11 - 11/07/11 | TLOW17 | B | DO | 09/20/11 - 09/27/11 |
| UKLE24 | B | DO | 04/19/11 - 04/26/11 | TLOW17 | B | DO | 10/04/11 - 10/13/11 |
| UKLE24 | B | DO | 05/03/11 - 05/10/11 | TLOW17 | B | DO | 10/18/11 - 10/25/11 |
| UKLE24 | B | DO | 05/17/11 - 05/24/11 | TLOW17 | B | DO | 11/01/11 - 11/07/11 |
| UKLE24 | B | DO | 06/03/11 - 06/14/11 | TLDW13 | B | DO | 03/28/11 - 04/05/11 |
| UKLE24 | C | DO | 06/14/11 - 06/23/11 | TLDW13 | B | SpC | 04/05/11 - 04/12/11 |
| UKLE24 | B | pH, SpC | 06/14/11 - 06/23/11 | TLDW13 | B | DO | 04/12/11 - 04/19/11 |
| UKLE24 | B | DO | 06/30/11 - 07/06/11 | TLDW13 | B | DO | 04/26/11 - 05/03/11 |
| UKLE24 | B | DO | 07/12/11 - 07/19/11 | TLDW13 | B | DO | 05/10/11 - 05/17/11 |
| UKLE24 | B | DO | 07/26/11 - 08/02/11 | TLDW13 | B | DO | 05/24/11 - 06/03/11 |
| UKLE24 | B | DO | 10/18/11 - 10/25/11 | TLDW13 | B | DO | 06/14/11 - 06/23/11 |
| UKLE24 | B | DO | 10/25/11 - 11/07/11 | TLDW13 | B | DO | 06/23/11 - 06/28/11 |
| WR21 | C | DO | 03/28/11 - 04/05/11 | TLDW13 | B | DO | 06/28/11 - 07/06/11 |
| WR21 | B | DO | 04/12/11 - 04/19/11 | TLDW13 | C | DO | 07/06/11 - 07/12/11 |
| WR21 | B | DO | 04/26/11 - 05/03/11 | TLDW13 | B | DO | 07/19/11 - 07/26/11 |

**Appendix D, continued.**

| Continuous Monitor Site | Data Quality Level | Parameter | Dates | Continuous Monitor Site | Data Quality Level | Parameter | Dates |
|---|---|---|---|---|---|---|---|
| TLDW13 | B | DO | 08/09/11 - 08/17/11 | TLEM9 | B | DO | 07/19/11 - 07/26/11 |
| TLDW13 | B | DO | 08/17/11 - 08/25/11 | TLEM9 | B | DO | 08/02/11 - 08/09/11 |
| TLDW13 | B | DO | 08/30/11 - 09/08/11 | GBEM4 | B | DO | 03/18/11 - 03/28/11 |
| TLDW13 | B | DO | 09/13/11 - 09/20/11 | GBEM4 | B | DO | 04/05/11 - 04/12/11 |
| TLDW13 | B | DO | 09/27/11 - 10/04/11 | GBEM4 | C | DO | 04/12/11 - 04/19/11 |
| TLDW13 | B | DO | 10/18/11 - 10/25/11 | GBEM4 | C | DO | 04/19/11 - 04/26/11 |
| TLEM9 | C | pH | 04/05/11 - 04/12/11 | GBEM4 | C | DO | 04/26/11 - 05/03/11 |
| TLEM9 | C | DO | 04/12/11 - 04/19/11 | GBEM4 | B | DO | 05/10/11 - 05/17/11 |
| TLEM9 | B | DO | 04/19/11 - 04/26/11 | GBEM4 | B | DO | 05/24/11 - 06/03/11 |
| TLEM9 | C | DO | 05/03/11 - 05/10/11 | GBEM4 | B | DO | 06/03/11 - 06/14/11 |
| TLEM9 | B | DO | 05/10/11 - 05/17/11 | GBEM4 | B | DO | 06/14/11 - 06/23/11 |
| TLEM9 | C | DO | 05/24/11 - 06/03/11 | GBEM4 | B | pH, DO | 07/06/11 - 07/12/11 |
| TLEM9 | B | DO | 06/23/11 - 06/28/11 | GBEM4 | B | DO | 07/19/11 - 07/26/11 |
| TLEM9 | B | pH, DO | 06/28/11 - 07/06/11 | GBEM4 | B | DO | 08/17/11 - 08/25/11 |
| TLEM9 | B | DO | 07/06/11 - 07/12/11 | | | | |