

DISSOLVED OXYGEN MONITORING IN KINGS RIVER AND LEATHERWOOD CREEK

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Dissolved Oxygen Monitoring in Kings River and Leatherwood Creek

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Executive Summary

The Clean Water Act (CWA) establishes the basic structure used to regulate water quality, requiring states to submit lists (i.e., 303(d) list) to the US Environmental Protection Agency on which water bodies violate applicable standards. In Arkansas, over 4,800 water bodies were on the 2008 303(d) list for not meeting the water quality standard for dissolved oxygen. The Upper White River Basin (UWRB) in northwest Arkansas had two stream reaches on this list of impaired water bodies due to low dissolved oxygen concentration – this included Leatherwood Creek and the Kings River. The objective of this project was to evaluate dissolved oxygen concentrations on these two reaches (Leatherwood Creek 916 and Kings River 042) relative to the applicable water quality standards (WQS).

Dissolved oxygen, water temperature, pH and conductivity were continuously recorded for 72-hr periods during data sonde deployments in the critical (mid-May through mid-September) and primary seasons (mid-September through mid-May) over calendar years 2012, 2013 and 2014; water samples were also collected at the beginning and end of each data sonde deployment. Dissolved oxygen concentrations were compared to the appropriate WQS from the Arkansas Pollution Control and Ecology Commission Regulation Number 2, which varied slightly between sites.

The dissolved oxygen concentration applicable to Leatherwood Creek were 6 mg/L during the primary season, except when water temperatures fall below 10°C. Dissolved oxygen concentrations at Leatherwood Creek were less than this applicable value only during the 2014 primary season. The critical season has dissolved oxygen limits of 5 mg/L (with some deviation allowed when water temperatures exceed 22°C) at Leatherwood Creek. Dissolved oxygen concentrations at this reach were below the applicable standard during the 2012 and 2014 critical seasons. The lows in dissolved oxygen concentration at Leatherwood Creek were likely driven by high rates of community respiration, which was in turn the result of the nutrient enrichment from the City of Eureka Springs municipal effluent discharge.

The dissolved oxygen limits for the Kings River were 6 mg/L during the primary season, and varied between 5 (upstream) and 6 mg/L (downstream) during the critical season depending on watershed area. The Kings River had dissolved oxygen concentrations in violation of the standard only once, during the critical season in 2012. The low dissolved oxygen concentrations observed in the Kings River appeared to be driven by hydrologic condition (extreme low flows) and high water temperatures. This also only occurred at the upstream end of the reach on the Kings River, with a site on the downstream end of the reach never showing depressed dissolved oxygen conditions.

Introduction

The Clean Water Act (CWA) establishes the basic structure used to regulate water quality. Under the CWA, States are required to assess water bodies relative to water-quality standards and designated beneficial uses and then to submit lists of impaired bodies every other year to the US Environmental Protection Agency (USEPA). In 2015, at least 4,800 water bodies were listed as impaired by dissolved oxygen across the US (USEPA, 2015). Aquatic species like fish and macroinvertebrates depend on adequate dissolved oxygen for survival. Low dissolved oxygen can lead to fish kills, reduced aquatic diversity, and nuisance smells from anaerobic conditions – ultimately, low dissolved oxygen concentrations result in water bodies not being able to meet the aquatic life designated use.

Low dissolved oxygen in flowing waters like streams and rivers is generally a symptom of some other hydrological or water-quality concern. For example, nutrient enrichment can result in increased algal growth – the algae (through photosynthesis) result in a net increase in dissolved oxygen during the daytime, but at night dissolved oxygen is consumed (through respiration) lowering the concentrations. The process of photosynthesis and respiration also influences the pH of the stream, where pH often increases during daytime and then decreases at night. This diurnal (daytime and nighttime) pattern is typical in streams and rivers, which is why dissolved oxygen concentrations and pH in streams need to be evaluated continuously over the course of several days.

Determination of water-quality impairments in Arkansas falls under the authority of the Arkansas Department of Environmental Quality (ADEQ) following the guidelines of the Arkansas Pollution Control and Ecology Commission Regulation Number 2 (APCEC, 2014). As assessed in 2008, almost 2,100 km of streams

and rivers in Arkansas were threatened or impaired by low dissolved oxygen concentrations. Two of those segments, equaling approximately 60 km of combined length, occur in the Upper White River Basin (HUC 11010001) in northwest Arkansas. The objective of this project was to evaluate dissolved oxygen concentrations, conductivity, pH and water temperature at four sites (two per reach) on two reaches (Leatherwood Creek 916 and Kings River 042) within the Upper White River Basin which appeared on the 2008 303(d) list for not meeting dissolved oxygen standards (ADEQ, 2008).

Study Area and Applicable Water-Quality Standards

The general study area is the Upper White River Basin (HUC 11010001), which is one of the HUC 8s in Arkansas identified as a priority watershed for the 2011-2016 Nonpoint Source Pollution (NPS) Management Plan (Arkansaswater.org, 2015). The UWRB is a 5,747 km² watershed that lies in northwest Arkansas crossing into Missouri, and this larger HUC 8 includes Beaver Lake and its watershed. The watershed is primarily forested (63.3%) and 24.7% is pasture and grassland, 6.7% is transitional, 2.1% is water, 1.5% is suburban, and 0.5% is urban (Arkansaswater.org, 2015). The two stream reaches studied in this project were on the Kings River and Leatherwood Creek, both of which flow into Table Rock Reservoir in Missouri (Figure 1). The Kings River is a natural and scenic waterway, as defined by ADEQ.

Prior to this project, reach 916 on Leatherwood Creek and reach 042 on the Kings River were on the 2010 303(d) list for not meeting the applicable water-quality standards for dissolved oxygen. Two sampling sites were selected along each reach (Figure 1), where one site was near the upstream portion of the reach and the other site was closer to the downstream end. Water samples were collected and specific conduct-

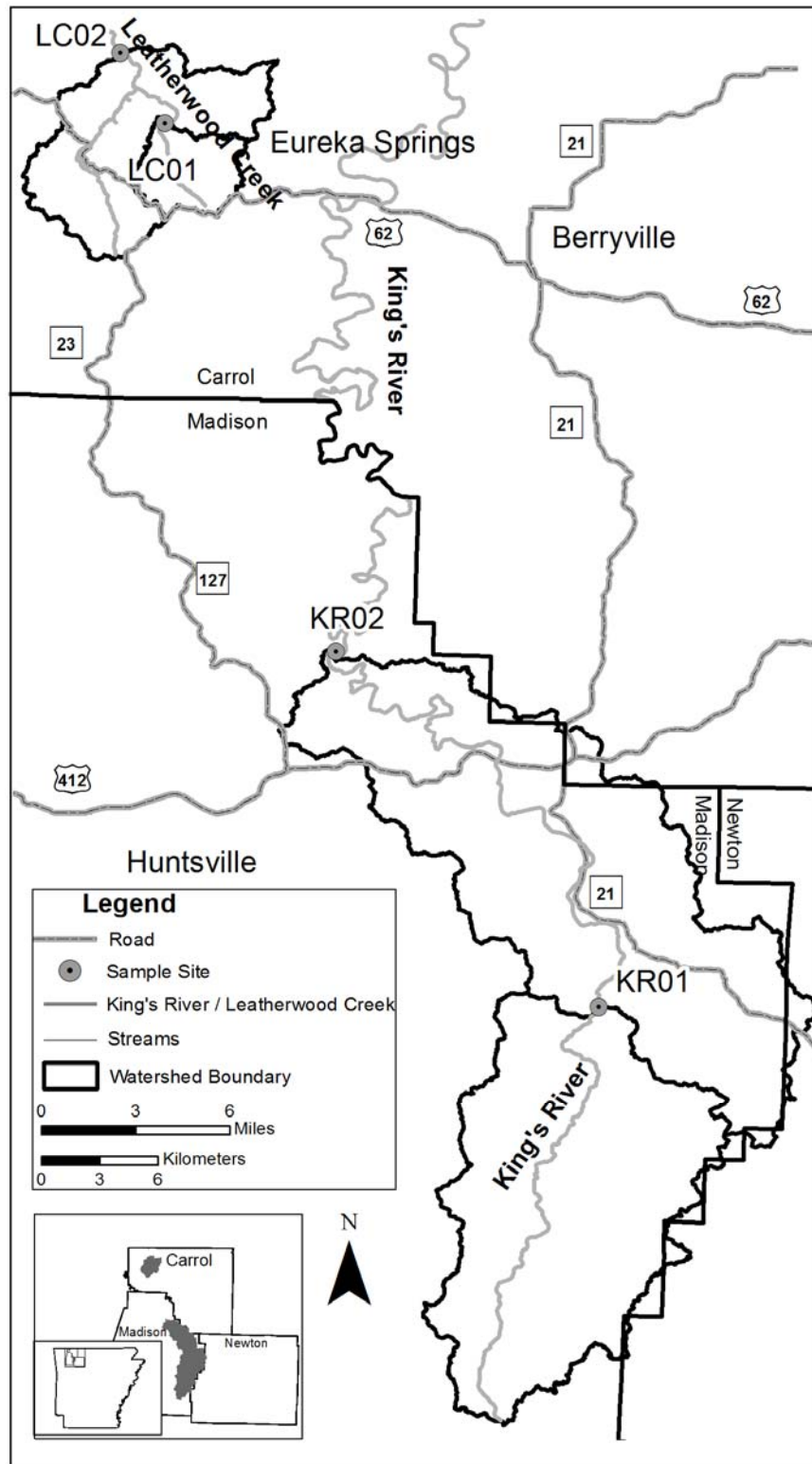


Figure 1. Map of the location of Leatherwood Creek study sites (LC01 and LC02) and King's River study sites (KR01 and KR02) within the Upper White River Watershed of northwest Arkansas.

ance, pH, temperature, and dissolved oxygen were continuously recorded for 72-hr periods during the deployments during the critical and primary seasons relative to the applicable water-periods during the deployments during the critical and primary seasons relative to the applicable water-quality standards for dissolved oxygen. The seasons are defined as:

- **Critical Season:** That period of the year when water temperatures exceed 22°C, which normally occurs from mid-May through mid-September and is normally hot, dry and after the majority of fish have spawned (APCEC, 2014).
- **Primary Season:** That period of the year when water temperatures are 22°C or less, normally from fall through spring or about mid-September through mid-May; it also includes the spawning season of most fish (APCEC, 2014).

This study was designed such that data was collected in these reaches twice during each season within calendar years 2012, 2013 and 2014.

The following dissolved oxygen standards are applicable to the two stream reaches in this project (Table 1), based on Regulation 2.505 for dissolved oxygen (APCEC, 2014). The regulation for dissolved oxygen is specific to the Ozark Highlands, and it varies between the primary and critical season, as well as with watershed size. The smaller watershed would be expected to support a fishery during the primary season, but it is assumed that insufficient water is present during the critical season. However, the regulation does require field verification in areas suspected of having substantial ground water inputs or perennial pools which may support unique aquatic biota. Also, if the smaller watersheds are found to have sufficient flow (i.e., 1 cfs or greater), including effluent discharges, then the critical season standard of 5 mg/L applies to these streams. If aquatic biota are present at

Table 1. Minimum dissolved oxygen water-quality standards for streams in the Ozark Highlands ecoregion from Arkansas Regulation Number 2, specifically Regulation 2.505 for dissolved oxygen (APCEC, 2014).

Ozark Highlands Ecoregion		
Waterbodies	Limit (mg/L)	
Streams	Primary	Critical
<16.1 km ² watershed	6	2
16.1 to 161 km ²	6	5
>161 km ² watershed	6	6
Trout Waters	6	6

flows less than 1 cfs, then such aquatic biota would be protected by the primary standard.

The regulation also has specific conditions which apply to effluent discharge limits, such as:

- “(A) *The primary season dissolved oxygen standard is to be met at a water temperature of 22°C (71.5°F) and at the minimum stream flow for that season. At water temperatures of 10°C (50°F), the dissolved oxygen standard is 6.5 mg/L.*
- (B) *During March, April and May, when background stream flows are 15 CFS or higher, the dissolved oxygen standard is 6.5 mg/L in all areas except the Delta Ecoregion, where the primary season dissolved oxygen standard will remain at 5 mg/L.*
- (C) *The critical season dissolved oxygen standard is to be met at maximum allowable water temperatures and at Q7-10 flows. However, when water temperatures exceed 22°C (71.6°F), a 1 mg/L diurnal depression will be allowed below the applicable critical standard for no more than 8 hours during any 24-hour period (APCEC, 2014).”*

Methods

At each sampling location, water samples were collected when the multi-probe data sondes (hereafter, 'data sondes'; YSI 6920 v2, TSI Inc., Yellow Springs, OH) were deployed or retrieved. Water samples were collected mid-stream near the vertical centroid of flow following an approved quality assurance project plan (QAPP). Water samples were collected following the field protocols outlined in the QAPP, delivered to the Arkansas Water Resources Center (AWRC) Water Quality Lab (WQL), and then analyzed using standard methods for each parameter (Table 2).

Flow was also measured during data sonde deployment and retrieval at each site. Depth and velocity reading were taken using a Flo-Mate Model 2000 Portable Flowmeter (Marsh-McBirney, Inc.) at near equal intervals across the stream cross section. The velocity, depth and interval width were multiplied together and then summed across the cross section to estimate discharge (cfs).

A data sonde (YSI 6920 v2, TSI Inc., Yellow Springs, OH) was deployed for 72-hour periods at each site for continuous recording of dissolved oxygen, temperature, pH, and specific conductance twice during each defined season under stable base flow conditions following the approved QAPP and standard operating procedures. The data sondes were programmed

to record the parameters every ten minutes and store the data in the internal memory. Each data sonde was deployed in a perforated PVC case for safety and security, and the case was anchored to a steel t-post which was driven into the stream substrate. The deployment case was situated in an area which was in constant contact with the main flow of the stream. After retrieval the data were downloaded from the data sondes and then transferred to an electronic database. Each sampling event included a standard suite of pre-deployment and post-deployment calibration checks, following the QAPP and standard operating procedures. The data, specifically dissolved oxygen concentrations after post-deployment calibration checks and drift adjustment, were evaluated against the dissolved oxygen standards as previously defined.

Results

Reach and Site Descriptions

Leatherwood Creek

Leatherwood Creek Reach 916 begins at the headwaters and continues downstream where it flows in to Table Rock Reservoir. The stream's watershed is primarily forested (87%) but the headwaters begin in the urban area (8%) of Eureka Springs. Pasture land use begins in the floodplain in the lower reaches, making up 5% of the total watershed area. The uppermost site in this reach (LC01) is downstream of the mixing

Table 2. Water-quality parameters analyzed for the water samples collected, and the analytical methods used, units reported, and method detection limits.

Parameter	Source/Method	Units	MDL
Nitrate-Nitrogen	EPA/300.0	mg/L	0.01
Chloride	EPA/300.0	mg/L	0.093
Soluble Reactive Phosphorus	EPA/365.1	mg/L	0.002
Total Phosphorus	APHA 4500PJ	mg/L	0.005
Total Nitrogen	APHA 4500PJ	mg/L	0.01
Total Suspended Solids	EPA/160.2	mg/L	5
Turbidity	EPA 180.1	NTU	NA
Conductivity	EPA 120.1	µS/cm	NA

zone of the City of Eureka Springs municipal wastewater treatment plant (WWTP), with a watershed area of approximately 16.1 km² (Table 3). The municipal facility is a minor level treatment plant, which is permitted to discharge 0.9 MGD into Leatherwood Creek. The second site (LC02) is at the lower end of the reach, upstream of the backwater influence of Table Rock Reservoir. The watershed area at this point along the reach is 71 km². Flow at the downstream site (LC02) was greater on average (12.8 cfs) during the primary season than that at the upstream site (LC01, 2.5 cfs) (Table 4). During the critical season, flows averaged under 1 cfs at both sites. The effluent discharge generally dominated flow at both sites (LC01 and LC02) during base flow conditions, leading to elevated nutrients. Observations of copious amounts of periphytic algal growth occurred at both sites during all seasons (see Figure 2), which likely resulted in the large diurnal swings in dissolved oxygen.

Kings River

Reach 042 on the Kings River begins in the headwaters of the river's watershed and ends just over 101 km downstream at the confluence of the Kings River and Dry Fork. The watershed is primarily forested (67%) with significant hay and pasture (29%) along the floodplains and scattered throughout. Urban land use

constitutes 4% of the watershed. The largest population center in the watershed is the unincorporated community of Kingston, which does not have a centralized WWTP. The uppermost site in this reach (KR01) has a watershed area of 167 km²; the downstream site (KR02) has a watershed area of almost 390 km². The composition of land use within the Kings River Watershed changes very little between sites, with no major tributaries or point sources; however, the physical, chemical and biological characteristics of the stream do shift downstream. The increase in watershed size from upstream (KR01) to downstream (KR02) results in average flow increasing from 68 to 113 cfs during the primary season and from 6 to 32 cfs during the critical season.

Water Chemistry

Leatherwood Creek

Leatherwood Creek had two sites along its reach (LC01 and LC02), and both sites were downstream of the effluent discharge from the City of Eureka Springs WWTP. The water chemistry at these sites reflected this influence. Nutrient concentrations in water samples from the upper site (LC01) were typically around double the concentration of that observed at the lower site (LC02) for all parameters (Tables 5 and 6). The geometric mean of nutrient concentra-

Table 3. Site name, ID, description, coordinates and watershed size in square km (km²) on Leatherwood Creek reach 916 and Kings River reach 042.

Site Name	Site ID	Site Description	Latitude	Longitude	Watershed Size (km ²)
Leatherwood 1	LC01	Leatherwood Creek Site 1 Highway 23 North Eureka Springs	36°25'51"N	93°44'03"W	16.1
Leatherwood 2	LC02	Leatherwood Creek Site 2 Highway 187 Low Water Bridge	36°27'51"N	93°45'19"W	71.0
Kings 1	KR01	Kings River Site 1 County Road 244 North Highway 74	36°01'26"N	93°32'08"W	167
Kings 2	KR02	Kings River Site 2 Marshall Ford County Road 1505	36°11'16"N	93°39'22"W	385

Table 4. Summary statistics for discharge (N=12) for primary season (October through May) and critical season (June through September) deployments for Leatherwood Creek and Kings River sites. The table includes the mean (Mean), minimum (Min), bottom quartile (25th), median (Med), upper quartile (75th), and maximum (Max) values in cubic feet per second (cfs).

		LC01	LC02	KR01	KR02
		cfs			
Primary Season	Mean	2.5	12.8	68.1	112.6
	Min	0.6	0.5	1.7	7.3
	25th	0.9	4.9	19.3	47.0
	Med	1.2	7.6	22.9	54.7
	75th	3.4	20.1	116.9	150.7
	Max	7.6	42.4	227.3	434.0

		LC01	LC02	KR01	KR02
		cfs			
Critical Season	Mean	0.6	0.7	5.8	32.1
	Min	0.4	0.0	0.0	1.7
	25th	0.4	0.4	0.2	5.8
	Med	0.6	0.5	0.9	10.0
	75th	0.7	0.7	9.5	47.4
	Max	0.9	2.3	24.8	105.7

tions across sites ranged from 0.03 mg/L total phosphorous (TP) and 0.54 mg/L total nitrogen (TN) at LC02 during the primary season to a high of 0.61 mg/L TP and 1.50 mg/L TN at LC01 during the critical season. Differences in concentrations between the primary and critical seasons were observed in most parameters, with the greater concentrations typically occurring in the critical season. This is most likely attributable to lower flows, which means less dilution of the effluent discharge, i.e. the WWTP has a bigger influence on the stream and water chemistry during lower flows. However, total organic carbon (TOC) concentrations were similar between sites and seasons at Leatherwood Creek.

Kings River

The Kings River also had two sites along its reach (KR01 and KR02), which spans almost 50 km from the headwaters downstream resulting in differences in chemistry, biology and physical characteristics of the river (i.e., from upstream to downstream). The differences in concentrations between the sites were mixed with both sites having low to very low values for most

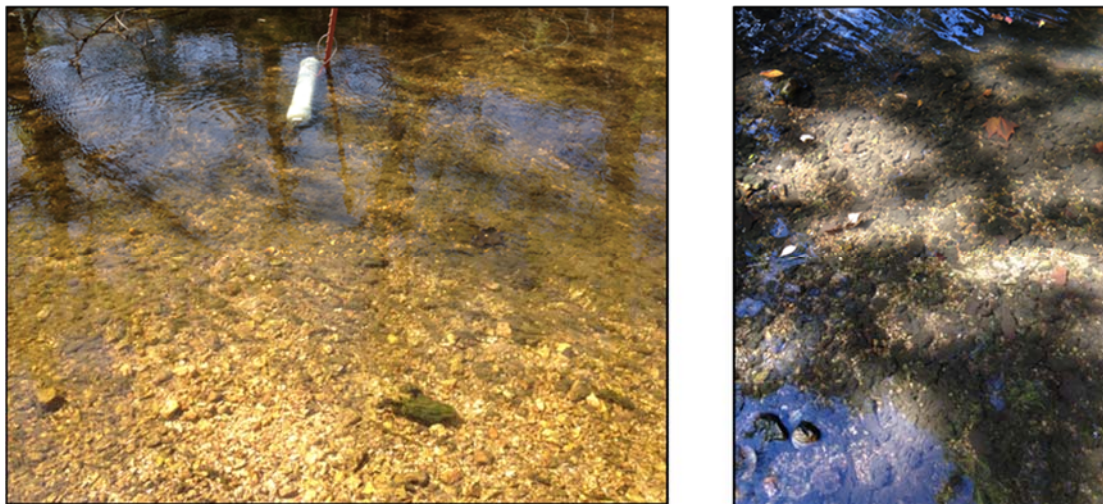


Figure 2. Photos from Leatherwood Creek Site 2 (LC02) of substrate with periphytic algal growth from April 2014 (photo on left) and August 2012 (photo on right).

Table 5. Water chemistry summary statistics (N=12) for primary season (October through May) and critical season (June through September) for Leatherwood Creek Site 1 (LC01). The table includes the geomean (Geo), minimum (Min), bottom quartile (25th), median (Med), upper quartile (75th), and maximum (Max) values in mg/L for chloride (Cl), sulfate (SO₄), nitrate (NO₃-N), total nitrogen (TN), ortho-phosphate (SRP), total phosphorus (TP), total suspended solids (TSS), and turbidity (Turb).

		Cl	SO ₄	NO ₃ -N	TN	TOC	SRP	TP	TSS	Turb
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	NTU
Primary Season	Geo	16.3	12.8	1.00	0.75	2.37	0.190	0.113	2.1	1.3
	Min	4.0	9.4	0.49	0.27	1.34	0.051	0.038	0.6	0.0
	25th	11.3	11.1	0.78	0.38	1.65	0.122	0.061	1.1	0.8
	Med	17.9	12.5	0.99	0.76	2.02	0.187	0.118	1.7	1.6
	75th	25.2	14.7	1.28	1.53	3.28	0.343	0.204	3.4	3.8
	Max	65.3	18.0	2.07	2.37	5.34	0.445	0.390	14.2	24.5
		Cl	SO ₄	NO ₃ -N	TN	TOC	SRP	TP	TSS	Turb
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	NTU
Critical Season	Geo	31.2	15.6	1.69	1.50	2.13	0.891	0.612	1.6	2.0
	Min	20.0	13.1	0.94	0.43	1.07	0.576	0.204	0.4	1.0
	25th	28.2	14.2	1.44	0.70	1.84	0.761	0.472	1.0	1.5
	Med	32.0	14.7	1.78	1.70	2.27	0.883	0.808	1.6	1.7
	75th	35.9	17.9	1.97	2.25	2.80	1.092	0.920	2.3	2.6
	Max	40.6	20.1	3.41	6.27	3.45	1.332	1.336	7.9	8.5

parameters. The concentrations in water samples from the upper site (KR01) were in general less than the values observed at the lower site (LC02) (Tables 7 and 8). The geometric mean of nutrient concentrations ranged from 0.012 mg/L TP at KR02 and 0.26 mg/L TN at KR01 during the primary season, to a high of 0.031 mg/L TP at KR01 during the primary season and 0.75 mg/L TN at KR02 during the critical season. Differences in mean concentrations between the primary and critical seasons, though small, were observed in most parameters, with the greater concentrations typically occurring in the critical season. This difference was more pronounced and consistent in the water samples collected from the downstream site (KR02).

Diurnal In-stream Parameters

Leatherwood Creek

On Leatherwood Creek the applicable dissolved oxygen concentration minimum standard for both sites is 6 mg/L during the primary season (i.e., generally mid-September through mid-May, when the water temperature is less than 22°C during seasonal base flow conditions) except when water temperatures fall below 10 °C, when the standard is 6.5 mg/L. The standard for both sites is 5 mg/L during the critical season (i.e., mid-May through mid-September, when the water temperature likely exceeds 22°C during seasonal base flow conditions) except when water temperatures rise above 22°C, when

Table 6. Water chemistry summary statistics (N=12) for primary season (October through May) and critical season (June through September) for Leatherwood Creek Site 2 (LC02). The table includes the geomean (Geo), minimum (Min), bottom quartile (25th), median (Med), upper quartile (75th), and maximum (Max) values in mg/L for chloride (Cl), sulfate (SO₄), nitrate (NO₃-N), total nitrogen (TN), ortho-phosphate (SRP), total phosphorus (TP), total suspended solids (TSS), and turbidity (Turb).

		Cl	SO ₄	NO ₃ -N	TN	TOC	SRP	TP	TSS	Turb
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	NTU
Primary Season	Geo	7.3	7.9	0.20	0.54	2.02	0.027	0.030	1.1	0.7
	Min	3.3	6.3	0.11	0.18	0.85	0.006	0.008	0.4	0.0
	25th	4.9	6.9	0.17	0.34	1.18	0.015	0.021	0.4	1.0
	Med	7.0	7.1	0.19	0.62	1.74	0.035	0.026	1.1	1.3
	75th	9.5	7.4	0.26	0.78	3.33	0.053	0.054	1.4	1.6
	Max	20.0	16.2	0.30	1.41	6.64	0.109	0.120	37.1	8.0
Critical Season	Geo	15.4	8.7	0.18	0.45	1.33	0.120	0.098	1.3	2.0
	Min	5.3	6.2	0.12	0.32	0.88	0.062	0.020	0.1	0.5
	25th	11.2	7.4	0.15	0.34	1.26	0.086	0.077	0.5	1.7
	Med	21.4	9.1	0.19	0.42	1.37	0.116	0.104	1.9	2.1
	75th	22.1	10.3	0.22	0.51	1.50	0.169	0.133	2.6	2.7
	Max	24.7	11.6	0.27	1.30	1.74	0.207	0.902	5.1	4.2

dissolved oxygen concentrations are allowed to dip 1 mg/L below this standard (to 4 mg/L) for no more than 8 hours. Multiple incidents of dissolved oxygen concentrations dropping below the applicable standard was recorded at both sites during the critical season and once during the primary season (Table 9). The following sections describe the dissolved oxygen and water temperature data specific to each deployment and during each season (i.e., primary and critical).

Primary Season

The dissolved oxygen standard during the primary season is 6 mg/L except when water temperatures fall below 10°C, in which case the applicable concentration is 6.5 mg/L. An initial

deployment of the data sondes was conducted at both Leatherwood Creek sites in April, 2012 and all dissolved oxygen concentrations were above 7 mg/L (Figure 3) but did show some diurnal variation (i.e., lesser concentrations of dissolved oxygen during night time, and greater concentrations during day time). Temperatures ranged from 12 to 20 °C (Figure 4), showing some fluctuations over 24-hr periods. Conductivity was just above 300 µS/cm at both sites, while pH ranged from 7.5 to 8.5 and was within the criteria for Ozark Highland streams (i.e., pH 6-9, APCEC, 2014). These conductivity and pH values were typical for the other primary season deployments at Leatherwood Creek, so these results will not be discussed for each deployment during the primary season (but see Appendix 1 for graphical data).

Table 7. Water chemistry summary statistics (N=12) for primary season (October through May) and critical season (June through September) for Kings River Site 1 (KR01). The table includes the geomean (Geo), minimum (Min), bottom quartile (25th), median (Med), upper quartile (75th), and maximum (Max) values in mg/L for chloride (Cl), sulfate (SO₄), nitrate (NO₃-N), total nitrogen (TN), ortho-phosphate (SRP), total phosphorus (TP), total suspended solids (TSS), and turbidity (Turb).

		Cl	SO ₄	NO ₃ -N	TN	TOC	SRP	TP	TSS	Turb
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	NTU
Primary Season	Geo	2.1	4.2	0.12	0.26	0.67	0.003	0.031	1.2	3.0
	Min	1.6	3.2	0.08	0.03	0.19	0.001	0.004	0.3	1.0
	25th	1.7	3.5	0.10	0.16	0.44	0.003	0.009	0.6	1.9
	Med	2.0	3.8	0.11	0.19	0.66	0.004	0.020	1.4	3.0
	75th	2.6	3.9	0.17	0.43	1.02	0.005	0.084	1.7	4.3
	Max	3.1	9.1	0.20	2.46	2.68	0.008	1.144	7.1	18.4
		Cl	SO ₄	NO ₃ -N	TN	TOC	SRP	TP	TSS	Turb
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	NTU
Critical Season	Geo	2.2	5.8	0.10	0.28	0.71	0.004	0.027	2.7	4.3
	Min	1.5	3.1	0.02	0.06	0.50	0.002	0.010	0.4	2.3
	25th	2.1	4.2	0.08	0.25	0.53	0.003	0.016	1.6	2.4
	Med	2.3	5.8	0.12	0.32	0.72	0.006	0.020	2.0	3.0
	75th	2.4	9.1	0.17	0.35	0.83	0.006	0.027	4.4	7.1
	Max	2.8	10.1	0.30	2.33	1.53	0.008	1.136	22.1	21.7

The second set of deployments during the primary season occurred in December 2012 and May 2013. In December 2012, dissolved oxygen concentrations were greater than 8 mg/L at both sites over the duration of the deployment (Figure 3); water temperatures were generally less than 10°C (Figure 4), so the applicable standard was 6.5 mg/L during this deployment. There were no dissolved oxygen violations recorded during the May 2013 deployment as well, though the downstream site (LC02) did show extreme variability in dissolved oxygen concentrations where values ranged from 8 to 15 mg/L in a 24 hour timeframe (Figure 3); all concentrations were greater than the applicable standard of 6 mg/L, since the water temperatures were greater than 10°C (Figure 4).

The third set of deployments in Leatherwood

Creek during the primary season were conducted in February and April 2014. During the February 2014 deployment, water temperatures stayed below 5°C (Figure 4) and dissolved oxygen concentration were greater than 10 mg/L (Figure 3) at both sites on Leatherwood Creek. However, violations of the dissolved oxygen standard were observed in the April 2014 (Table 9), where dissolved oxygen concentrations were below 6 mg/L when water temperatures were less than 22°C; this only occurred at the upstream site (LC01) on Leatherwood Creek. Dissolved oxygen concentrations also showed extremely high diurnal fluctuations at both sites during the April 2013 deployment.

A final deployment during the primary season was conducted in December 2014. Dissolved oxygen concentrations ranged from approx-

Table 8. Water chemistry summary statistics (N=12) for primary season (October through May) and critical season (June through September) for Kings River Site 2 (KR02). The table includes the geomean (Geo), minimum (Min), bottom quartile (25th), median (Med), upper quartile (75th), and maximum (Max) values in mg/L for chloride (Cl), sulfate (SO₄), nitrate (NO₃-N), total nitrogen (TN), ortho-phosphate (SRP), total phosphorus (TP), total suspended solids (TSS), and turbidity (Turb).

		Cl	SO ₄	NO ₃ -N	TN	TOC	SRP	TP	TSS	Turb
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	NTU
Primary Season	Geo	3.5	5.6	0.77	0.42	0.99	0.003	0.012	1.6	1.7
	Min	2.4	4.4	0.47	0.11	0.44	0.001	0.002	0.2	0.0
	25th	2.9	4.8	0.62	0.16	0.67	0.003	0.008	1.3	2.1
	Med	3.6	5.3	0.72	0.70	0.86	0.004	0.013	1.9	2.6
	75th	3.9	6.5	0.92	0.92	1.44	0.005	0.020	2.4	3.1
	Max	5.3	7.6	1.46	1.41	2.59	0.008	0.048	3.1	7.7
Critical Season	Geo	3.9	4.3	0.55	0.75	0.65	0.004	0.030	3.7	5.4
	Min	2.0	3.0	0.26	0.18	0.01	0.002	0.014	2.0	3.1
	25th	3.6	3.5	0.36	0.49	0.65	0.003	0.020	2.6	3.4
	Med	4.2	4.4	0.42	0.65	0.83	0.005	0.022	3.2	4.0
	75th	4.4	5.0	1.03	1.72	0.91	0.007	0.027	5.2	6.5
	Max	7.6	7.3	1.66	2.99	2.70	0.010	1.344	13.7	39.6

imately 8.5 to 14 mg/L across all sites (Figure 3) with water temperatures ranging from 8 to 15 °C (Figure 4). No potential violations were observed in the applicable dissolved oxygen standards during this final deployment.

Critical Season

For the study sites on Leatherwood Creek, the dissolved oxygen standard during the critical season is 5 mg/L except when water temperatures rise above 22°C, when dissolved oxygen concentrations are allowed to dip 1 mg/L below this standard (to 4 mg/L) for no more than 8 hours. The first deployment during the critical season occurred in June 2012. At Leatherwood Creek, the upstream site (LC02) had low dissolved oxygen concentrations, rarely reaching

above 6 mg/L during the day and falling below 2.5 mg/L at night (Figure 5). However, the downstream site (LC01) had dissolved oxygen concentrations that showed some diurnal fluctuation but were above 6 mg/L throughout the day and night. Water temperatures at both sites ranged from 20 to 25°C during this deployment (Figure 6), and temperatures decreased further downstream of the effluent discharge.

The second deployment for this critical season was during July 2012. Dissolved oxygen concentrations at the upstream site (LC01) fluctuated diurnally, dipping below 6 mg/L at night but remaining greater than or equal to approximately 5 mg/L (Figure 5). Again, the downstream site (LC02) had dissolved oxygen concentration that were depressed relative to

Table 9. Potential violations of the applicable dissolved oxygen water-quality standards for Leatherwood Creek and Kings River, showing the site, date, time, season, minimum dissolved oxygen measured (min DO), minimum dissolved oxygen standard (DO min standard), and consecutive time dissolved oxygen was below minimum standard (time below min standard); a (*) indicates that the time below the minimum standard ended because the data sonde was retrieved and not because concentrations increased above the minimum standard.

Site	Date	Time	Season	Min DO (mg/L)	DO Min Standard (mg/L)	Time Below Min Standard (hr)
LC02	06/19/2012	21:10	Critical	2.44	5	18.3
LC02	06/20/2012	21:20	Critical	2.89	5	15.2
LC02	06/21/2012	22:00	Critical	3.26	5	12.0*
KR01	06/21/2012	04:30	Critical	4.05	5	5.2
KR01	06/22/2012	05:00	Critical	4.06	5	4.5
LC02	07/02/2012	22:25	Critical	1.03	5	16.7
LC02	07/03/2012	21:40	Critical	1.03	5	38.0*
KR01	07/03/2012	02:00	Critical	3.34	5	9.8
KR01	07/04/2012	02:10	Critical	2.36	5	10.3
KR01	07/05/2012	00:35	Critical	2.13	5	12.9
LC01	04/22/2014	20:40	Primary	5.60	6	1.0
LC01	04/23/2014	20:30	Primary	4.85	6	5.8
LC01	04/24/2014	03:30	Primary	5.73	6	1.8
LC02	08/20/2014	03:00	Critical	4.04	5	8.2
LC02	08/21/2014	04:20	Critical	3.82	5	7.2
LC02	08/22/2014	03:00	Critical	3.52	5	6.8*

the site further upstream. The dissolved oxygen concentrations at LC02 ranged from 1 to 6 mg/L across the 72-hour deployment, rarely even reaching the minimum standard (Figure 5). Water temperatures were between 24 and 27°C, where temperatures were consistently lower upstream (Figure 6).

The deployments during the second critical season were conducted in August and September 2013. The dissolved oxygen concentrations at the downstream site (LC02) on Leatherwood Creek were below 5 mg/L for a period of almost 4 hours in August 2013, whereas the upstream site (LC01) remained above 6 mg/L; both sites showed fluctuations between day and night (Figure 5). The second

deployment during the critical season was in September 2013, showing diurnal variation and results similar to the August 2013 deployment. The dissolved oxygen concentrations at the downstream site (LC02) dropped below 5 mg/L but for less than 8 hours at a time, whereas concentrations at the upstream site (LC01) were above 6 mg/L through the deployment (Figure 5). The applicable standard for dissolved oxygen during the critical season is 5 mg/L, but the water temperatures (especially at the upstream site, LC02) were often greater than 22°C (Figure 6). Thus, these incidents did not meet the criteria for violation since the dissolved oxygen concentrations did not remain below the standard for more than 8 hours and did not go below 4 mg/L.

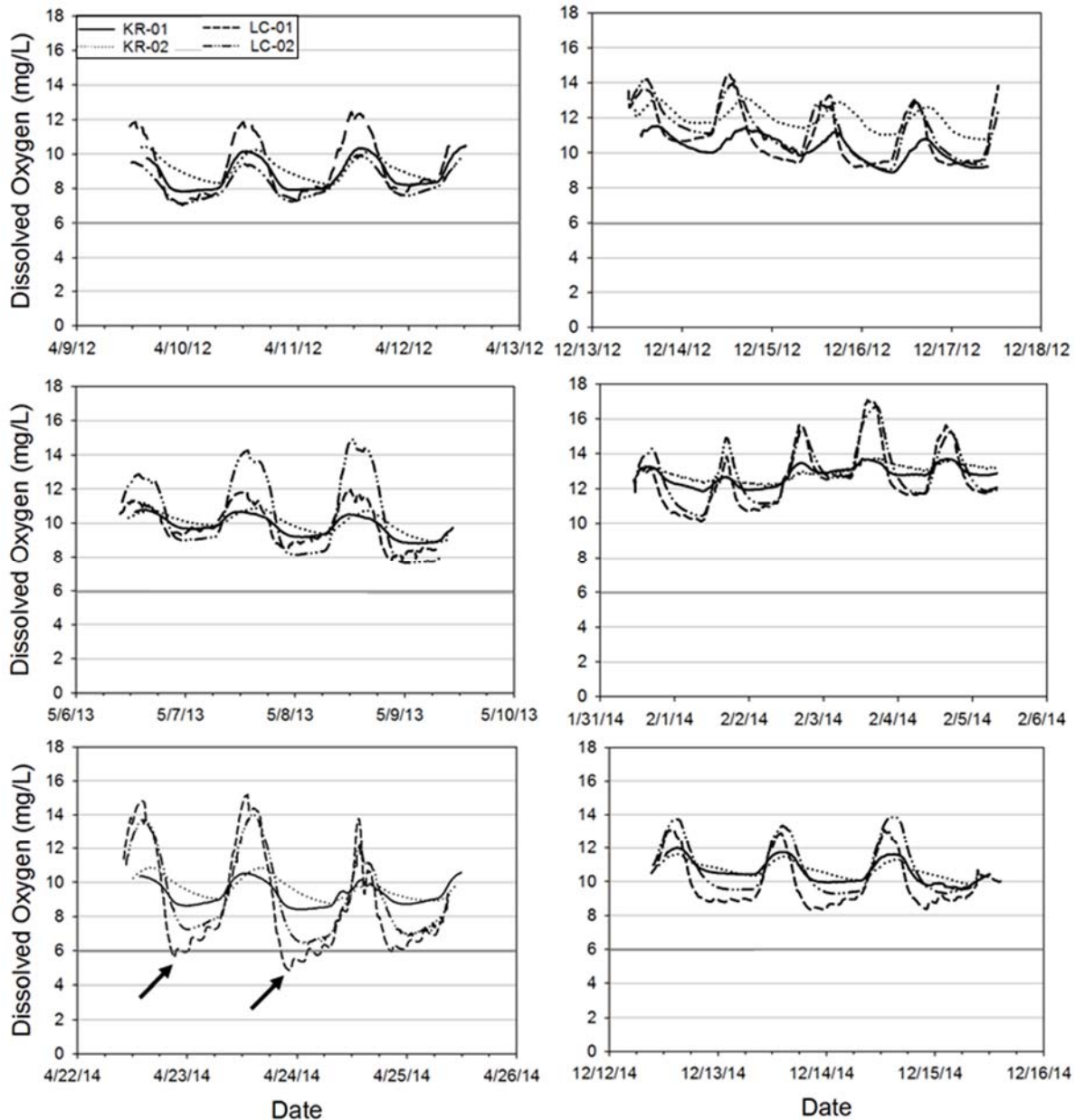


Figure 3. Dissolved oxygen data (mg/L) collected from datasondes during each deployment during the primary season (mid-September through mid-May) during the study period (calendar years 2012, 2013 and 2014) for the two sites in Leatherwood Creek (LC01 and LC02) and the two sites in Kings River (KR01 and KR02). The minimum DO standard during the primary season is 6 mg/L except when water temperatures fall below 10 °C, in which case the standard is 6.5 mg/L. Areas where dissolved oxygen concentrations dropped below the applicable standard are shown with a black arrow.

The first deployment during the 2014 critical season was conducted in August, and potential violations of the dissolved oxygen standard were again observed at the downstream site (LC02) on

Leatherwood Creek. At the downstream site (LC02), dissolved oxygen concentrations dipped as low as 4 mg/L (Figure 5) while temperature averaged around 25°C (Figure 6); the dissolved

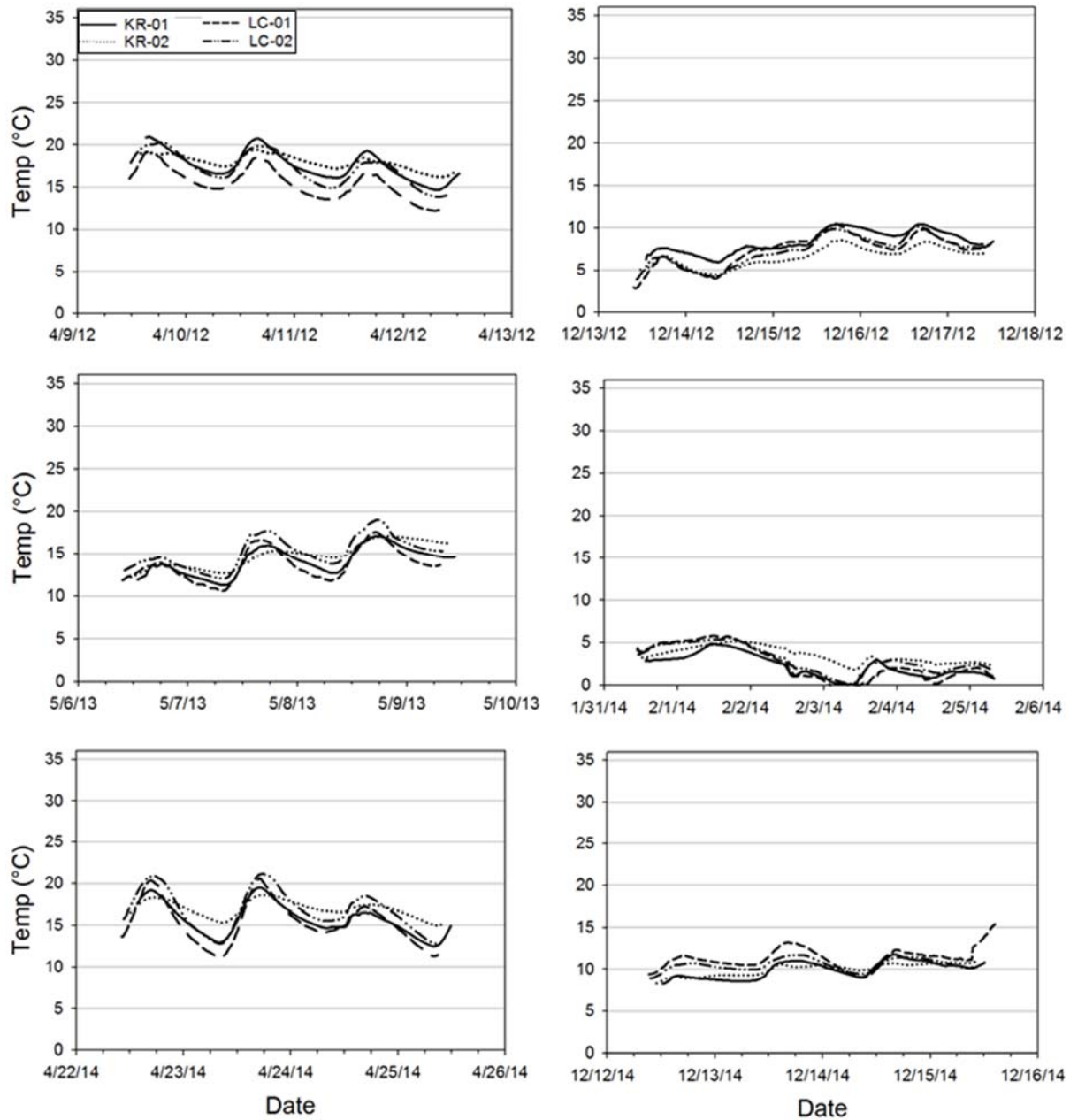


Figure 4. Continuous water temperature (°C) data collected from datasondes during each deployment during the primary season (mid-September through mid-May) during the study period (calendar years 2012, 2013 and 2014) for the two sites in Leatherwood Creek (LC01 and LC02) and the two sites in Kings River (KR01 and KR02).

oxygen upstream (LC01) remained above 6 mg/L during this deployment. The second deployment during this critical season occurred in September 2014. The weather was unseasonably cool resulting in average water temperature

of less than 20°C during this deployment (Figure 6), and dissolved oxygen concentrations were above the minimum standards for the entire deployment (Figure 5).

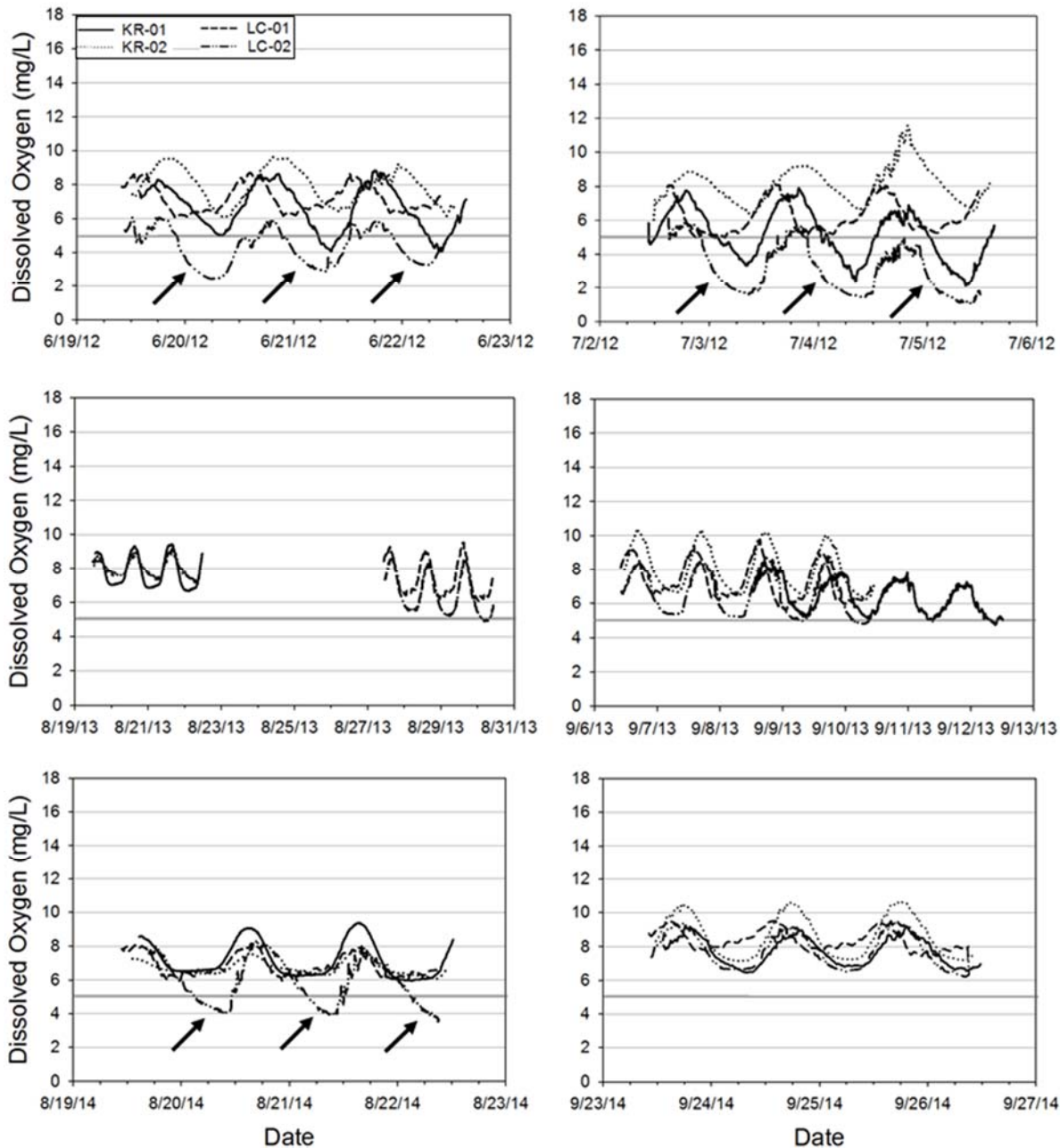


Figure 5. Continuous dissolved oxygen data (mg/L) collected from datasondes during each deployment during the critical season (mid-May through mid-September) during the study period (calendar years 2012, 2013 and 2014) for the two sites in Leatherwood Creek (LC01 and LC02) and the two sites in Kings River (KR01 and KR02). The minimum dissolved oxygen standard during the critical season is 5 mg/l at KR01, LC01, and LC02 and 6 mg/L at KR02 except when water temperatures rise above 22°C, in which case dissolved oxygen concentrations are allowed to dip 1 mg/L below this standard for no more than 8 hours. Areas where dissolved oxygen concentration dropped below the applicable standard are shown with a black arrow.

Kings River

For study sites on the Kings River, the applicable

dissolved oxygen standard is 6 mg/L during the primary season (i.e., generally mid-September through mid-May, when the water temperature

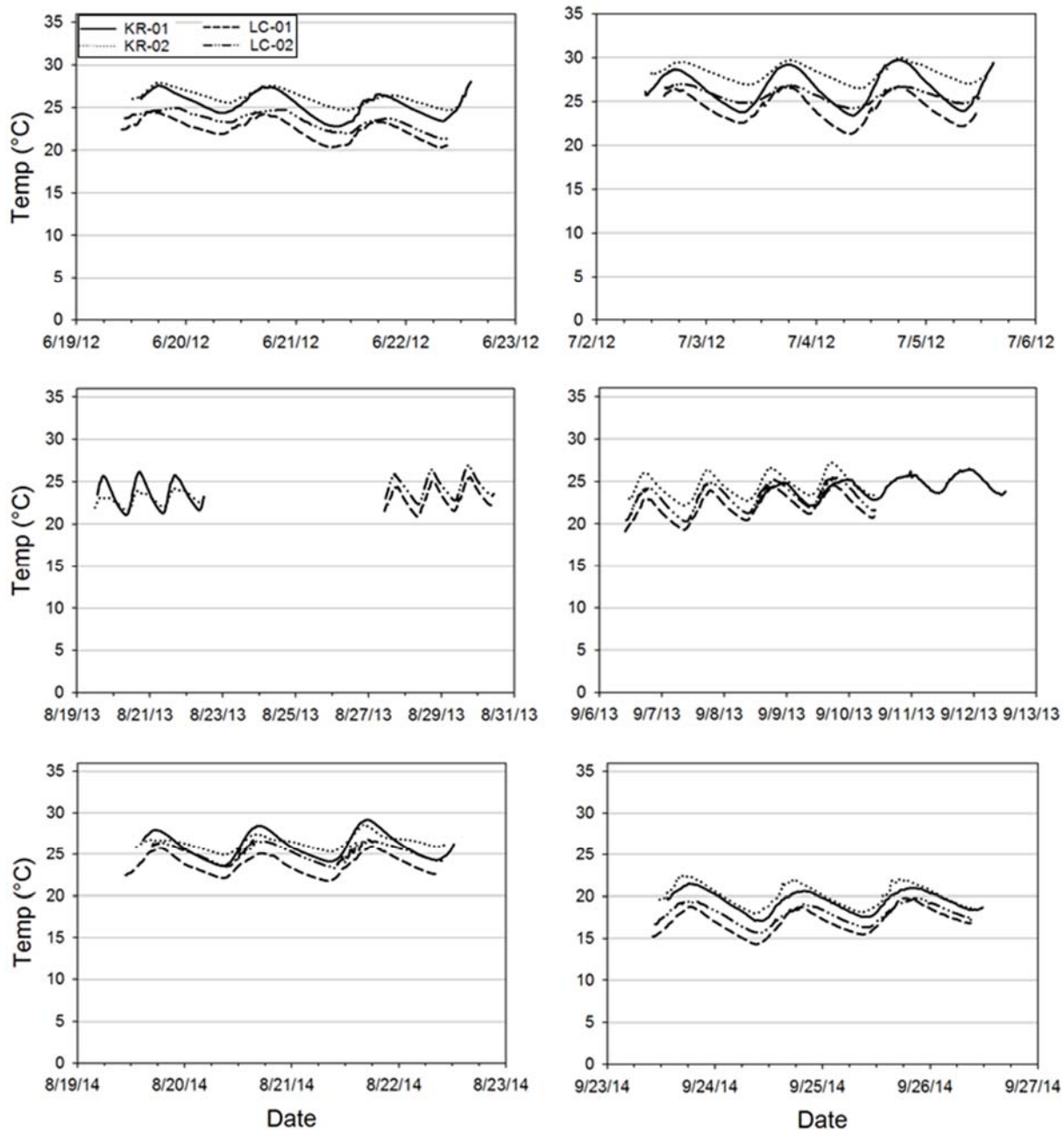


Figure 6. Continuous water temperature (°C) data collected from datasondes during each deployment during the critical season (mid-May through mid-September) during the study period (calendar years 2012, 2013 and 2014) for the two sites in Leatherwood Creek (LC01 and LC02) and the two sites in Kings River (KR01 and KR02).

is less than 22°C during seasonal base-flow conditions). During the critical season (i.e., mid-May through mid-September, when the water temperature likely exceeds 22°C during seasonal base-flow conditions), the applicable dissolved oxygen standard is different between the sites,

where the minimum DO standard is 5 mg/L at KR01 and 6 mg/L at KR02. Dissolved oxygen concentrations dropped below the applicable standard at KR01 once during the critical season and close to remaining below the standard for 8 hours during another critical season deployment

(Table 9). No potential violations were observed at the downstream Kings River site (KR02). The dissolved oxygen and water temperature data specific to each deployment and season is discussed below.

Primary Season

The primary season minimum DO standard is 6 mg/L except when water temperatures fall below 10 °C, in which case the standard is 6.5 mg/L. An initial deployment of the data sondes was conducted at both Kings River sites in April 2012 and all dissolved oxygen concentrations were close to or greater than 8 mg/L at both sites (Figure 3). However, both KR01 and KR02 did show some diurnal variation (i.e., lesser concentrations during nighttime, and greater concentrations during daytime). Temperatures ranged from 15 to 20 °C (Figure 4), showing some fluctuations over 24-hr periods. Conductivity was approximately 200 µS/cm at both sites, while pH ranged from 7.3 to 8.3 and was within the criteria for Ozark Highland streams (i.e., pH 6-9, APCEC, 2014). These conductivity and pH values were typical for the other primary season deployments at Kings River, so these results will not be discussed for each primary season deployment (see Appendix 1 for graphical data).

The second set of deployments during the primary season occurred in December 2012 and May 2013. In December 2012, dissolved oxygen concentrations were greater than 8 mg/L at both sites over the duration of the deployment (Figure 3); water temperature were generally less than 10°C (Figure 4), so the applicable standard would have been 6.5 mg/L during this deployment. There were no dissolved oxygen violations recorded at either of the Kings River sites during the May 2013 deployment as well; all concentrations were greater than the applicable standard of 6 mg/L, since the water temperatures were greater than 10°C.

The third set of deployments during the primary season were conducted in February and April 2014. During the February 2014 deployment, water temperatures stayed below 5°C (Figure 4) and dissolved oxygen concentrations were greater than 12 mg/L (Figure 3), well above the applicable limit of 6.5 mg/L respective to measured water temperatures. During the April 2014 deployment, dissolved oxygen concentrations were above 8 mg/L (Figure 3), well above the 6 mg/L minimum standard.

A final deployment during the primary season was conducted in December 2014. Dissolved oxygen concentrations were above 10 mg/L at both sites (Figure 3) with water temperatures ranging from 8 to 15 °C (Figure 4). No potential violations were observed in the applicable dissolved oxygen standards during this final deployment.

Critical Season

For the study sites on Kings River, the dissolved oxygen standard during the critical season is 5 mg/L except when water temperatures rise above 22°C, when dissolved oxygen concentrations are allowed to dip 1 mg/L below this standard (to 4 mg/L) for no more than 8 hours. The first critical season deployment occurred in June 2012. At the upper site on the Kings River (KR 01) dissolved oxygen concentrations fell below 5 mg/L, but never fell below 4 mg/L (Figure 5). Deviations below the minimum standard (5 mg/L) lasted less than 8 hours and therefore did not constitute a violation. A final deployment for summer 2012 was made during July. Dissolved oxygen concentrations were greater than 5 mg/L at downstream site, KR02 (Figure 5). Lower dissolved oxygen concentrations were observed at KR01 where they ranged from 2.1 to 7.9 mg/L (Figure 5), which constituted a violation of the critical season standard.

The deployments during the second critical season were conducted in August and September 2013. Dissolved oxygen concentrations remained above 6 mg/L at both sites throughout the entire deployment (Figure 5). The second critical deployment in September resulted in results similar to the August deployment. Dissolved oxygen concentrations remained above 6 mg/L at the downstream site, KR02 (Figure 5). However, dissolved oxygen concentrations at the upstream site, KR01, were below 5 mg/L but for less than 8 hours at a time (Figure 5), thus not violating the criteria with water temperatures averaging above 22°C (Figure 6).

The first deployment during the 2014 critical season was conducted in August. Dissolved oxygen concentrations remained above 6 mg/L at both sites (Figure 5) while temperatures averaged 25°C (Figure 6). The second deployment during this critical season occurred in September 2014. The weather was unseasonably cool resulting in average water temperature of less than 20°C during this deployment (Figure 6), and dissolved oxygen concentrations were above the minimum standards for the entire deployment (Figure 5).

Summary and Considerations

Dissolved oxygen concentrations measured during this project showed potential violations of minimum criteria in both Leatherwood Creek and the Kings River (Table 9). In summary, the potential violations are:

- In Leatherwood Creek, at the upstream study site (LC01), dissolved oxygen concentrations were below the applicable water-quality standard (6 mg/L) only during the April 2014 primary season deployment.
- In Leatherwood Creek, at the downstream site (LC02), potential violations of the applicable water-quality standard

for dissolved oxygen occurred during three deployments, with all occurring during the critical season (June and July 2012 and August 2014).

- In Kings River, only the upstream site (KR01) demonstrated a potential violation of the water-quality standard for dissolved oxygen during the critical season (July 2013).

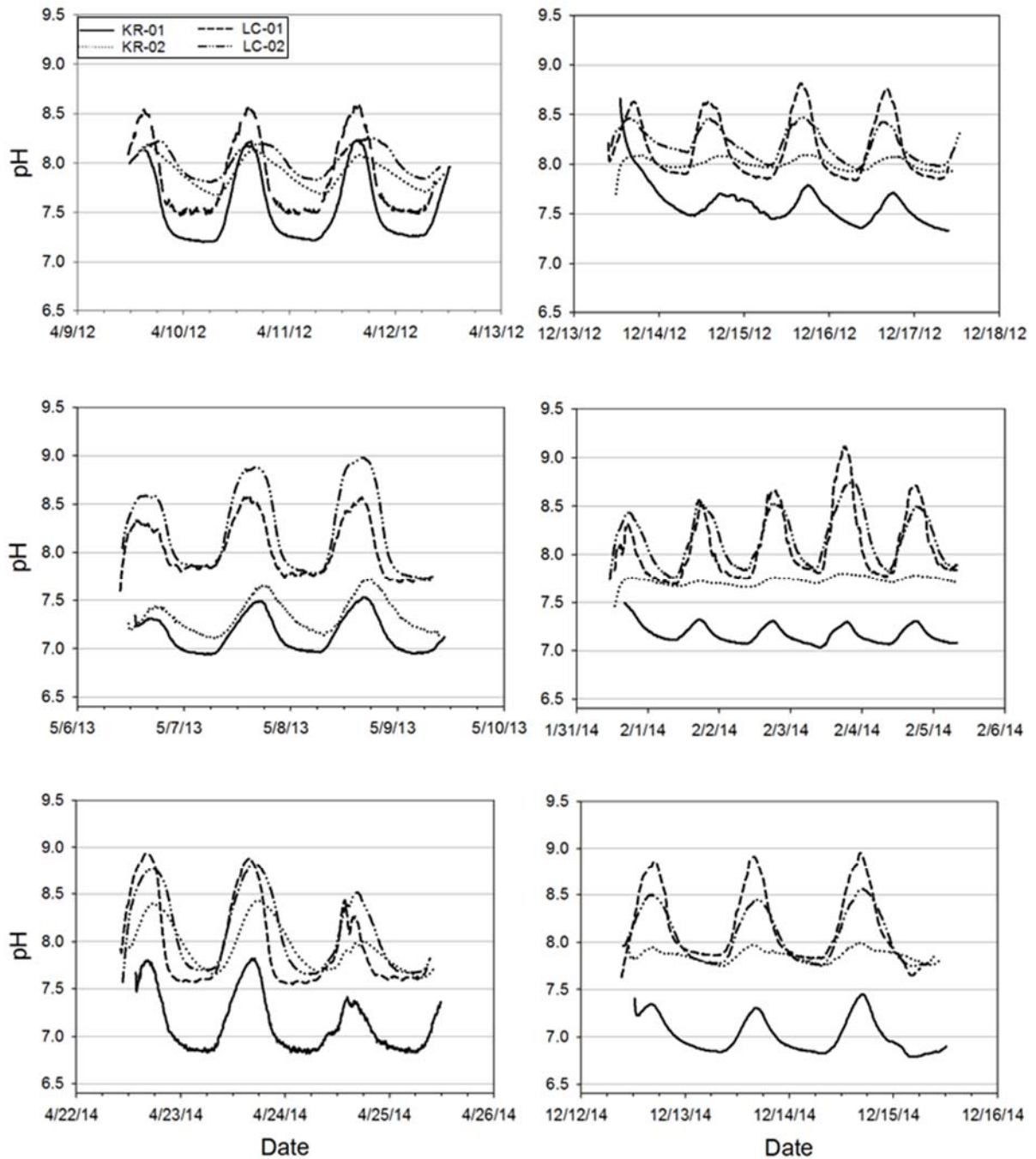
All sites showed diurnal variations in dissolved oxygen concentrations, indicating the important influence of photosynthesis and community respiration in these reaches. Strong diurnal variations are often symptomatic of nutrient enrichment, which might be the case for Leatherwood Creek which receives effluent discharge. However, Kings River site KR01 had relatively low nutrient concentrations, suggesting that hydrologic conditions might also accentuate depression of dissolved oxygen concentrations.

References

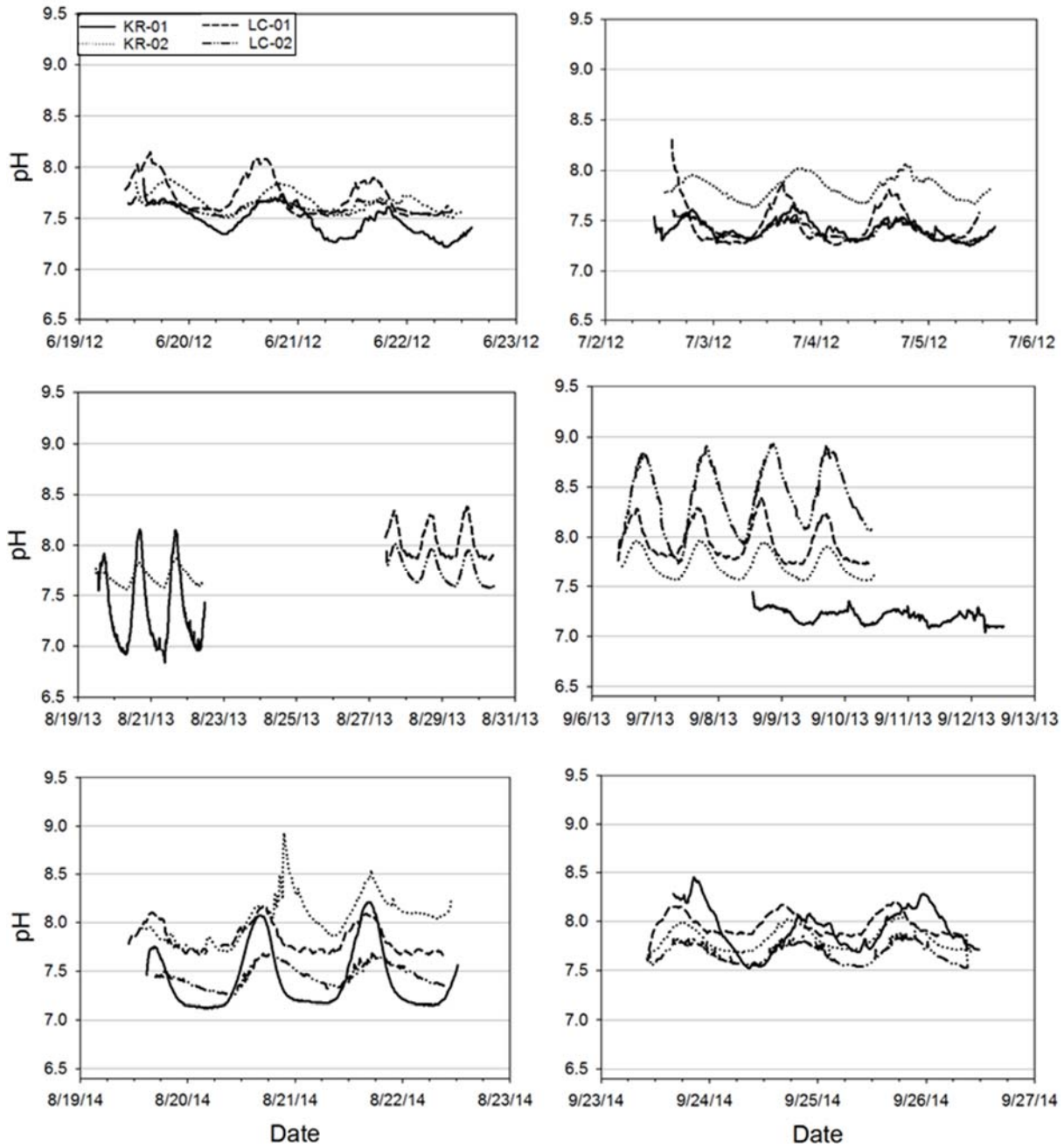
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Appendix 1. Continuous pH data collected from datasondes during each deployment during the critical (mid-May through mid-September) and primary seasons (mid-September through mid-May) during the study period (calendar years 2012, 2013 and 2014) for the two sites in Leatherwood Creek (LC01 and LC02) and the two sites in Kings River (KR01 and KR02).

Primary Season Deployments

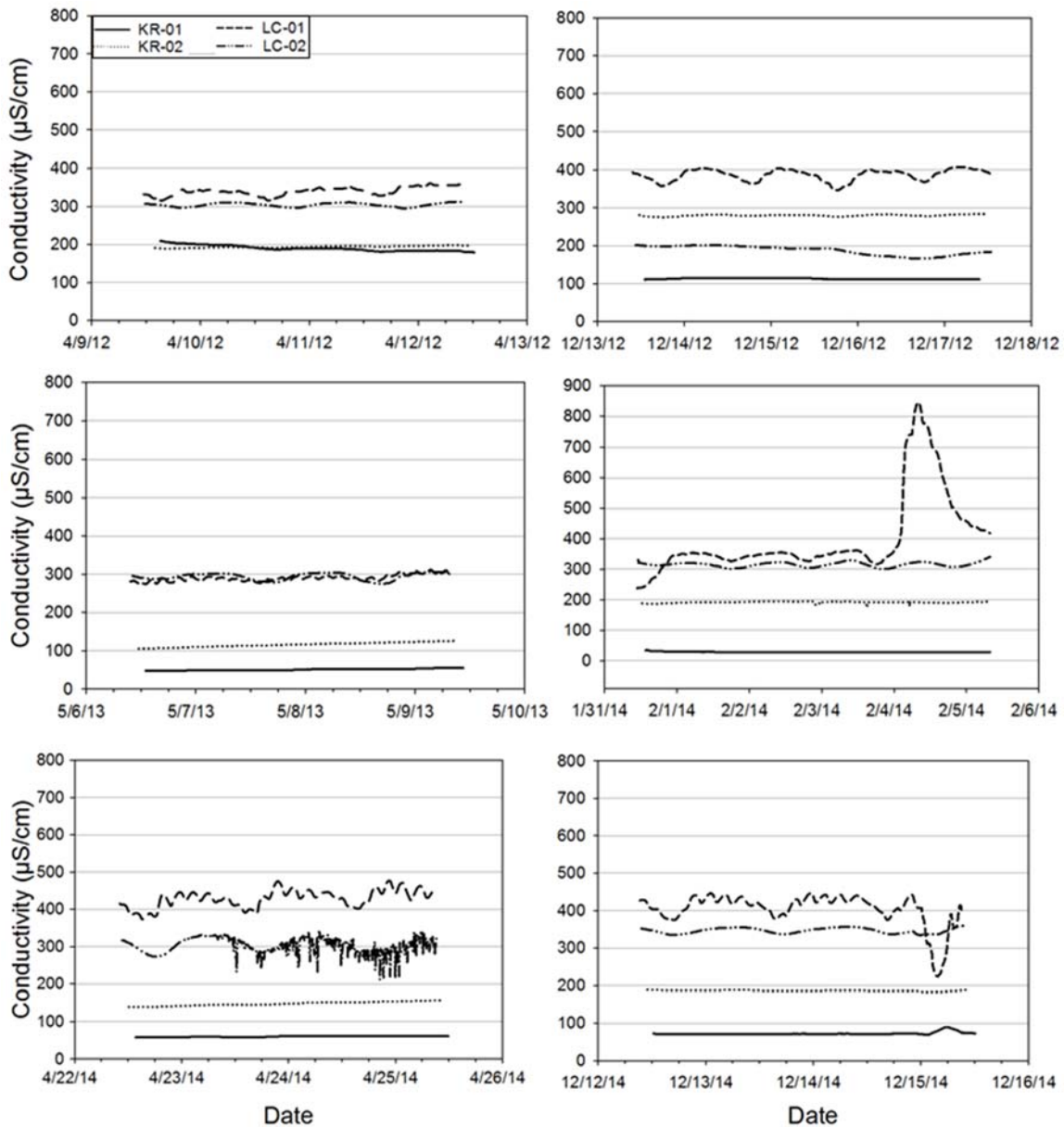


Critical Season Deployments



Appendix 2. Continuous conductivity data collected from datasondes during each deployment during the critical (mid-May through mid-September) and primary seasons (mid-September through mid-May) during the study period (calendar years 2012, 2013 and 2014) for the two sites in Leatherwood Creek (LC01 and LC02) and the two sites in Kings River (KR01 and KR02).

Primary Season Deployment



Critical Season Deployments

