Prepared in Cooperation with the U. S. Bureau of Reclamation

Water Velocity and Suspended Solids Measurements by In-Situ Instruments in Upper Klamath Lake, Oregon

Open-File Report 2007–1279

U.S. Department of the Interior
U.S. Geological Survey

Prepared in Cooperation with the U. S. Bureau of Reclamation

Water Velocity and Suspended Solids Measurements by In-Situ Instruments in Upper Klamath Lake, Oregon

By Jeffrey W. Gartner, Roy E. Wellman, Tamara M. Wood, and Ralph T. Cheng

Open-File Report 2007–1279

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2007

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth,
its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Gartner, J. W., Wellman, R. E., Wood, T. M., and Cheng, R. T., 2007, Water velocity and suspended solids measurements by in-situ instruments in Upper Klamath Lake, Oregon: U. S. Geological Survey Open-File Report 2007-1279, viii + 137 pp.

Contents

Figures

Tables

Conversion Factors, Abbreviations, and Acronyms

SI to Inch/Pound

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)
	Area	
square meter (m^2)	0.0002471	acre
square kilometer (km^2)	247.1	acre
square meter (m^2)	10.76	square foot (ft^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)
cubic meter per second (m^3/s)	22.83	million gallons per day (Mgal/d)
kilometer per hour (km/h)	0.6214	mile per hour (mi/h)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32
Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

Abbreviations

deg. Degrees
Deg. T, Degrees True
kHz, kiloHertz

Acronyms

ADCP, Acoustic Doppler Current Profiler
Bin, A depth cell from an ADCP
GPS, Global Positioning System
LISST, Laser In-situ Scattering and Transmissometry
SSC, Suspended Solids Concentration
USGS, U.S. Geological Survey

Julian Date Calendar – non leap years

For nonleap years														
Day	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Day**
1	-30	1	32	60	91	121	152	182	213	244	274	305	335	1
2	-29	2	33	61	92	122	153	183	214	245	275	306	336	2
3	-28	3	34	62	93	123	154	184	215	246	276	307	337	3
4	-27	4	35	63	94	124	155	185	216	247	277	308	338	4
5	-26	5	36	64	95	125	156	186	217	248	278	309	339	5
6	-25	6	37	65	96	126	157	187	218	249	279	310	340	6
7	-24	7	38	66	97	127	158	188	219	250	280	311	341	7
8	-23	8	39	67	98	128	159	189	220	251	281	312	342	8
9	-22	9	40	68	99	129	160	190	221	252	282	313	343	9
10	-21	10	41	69	100	130	161	191	222	253	283	314	344	10
11	-20	11	42	70	101	131	162	192	223	254	284	315	345	11
12	-19	12	43	71	102	132	163	193	224	255	285	316	346	12
13	-18	13	44	72	103	133	164	194	225	256	286	317	347	13
14	-17	14	45	73	104	134	165	195	226	257	287	318	348	14
15	-16	15	46	74	105	135	166	196	227	258	288	319	349	15
16	-15	16	47	75	106	136	167	197	228	259	289	320	350	16
17	-14	17	48	76	107	137	168	198	229	260	290	321	351	17
18	-13	18	49	77	108	138	169	199	230	261	291	322	352	18
19	-12	19	50	78	109	139	170	200	231	262	292	323	353	19
20	-11	20	51	79	110	140	171	201	232	263	293	324	354	20
21	-10	21	52	80	111	141	172	202	233	264	294	325	355	21
22	-9	22	53	81	112	142	173	203	234	265	295	326	356	22
23	-8	23	54	82	113	143	174	204	235	266	296	327	357	23
24	-7	24	55	83	114	144	175	205	236	267	297	328	358	24
25	-6	25	56	84	115	145	176	206	237	268	298	329	359	25
26	-5	26	57	85	116	146	177	207	238	269	299	330	360	26
27	-4	27	58	86	117	147	178	208	239	270	300	331	361	27
28	-3	28	59	87	118	148	179	209	240	271	301	332	362	28
29	-2	29		88	119	149	180	210	241	272	302	333	363	29
30	-1	30		89	120	150	181	211	242	273	303	334	364	30
31		31		90		151		212	243		304		365	31

Julian Date Calendar—leap years

For leap years														
Day	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Day**
1	-30	1	32	61	92	122	153	183	214	245	275	306	336	1
2	-29	2	33	62	93	123	154	184	215	246	276	307	337	2
3	-28	3	34	63	94	124	155	185	216	247	277	308	338	3
4	-27	4	35	64	95	125	156	186	217	248	278	309	339	4
5	-26	5	36	65	96	126	157	187	218	249	279	310	340	5
6	-25	6	37	66	97	127	158	188	219	250	280	311	341	6
7	-24	7	38	67	98	128	159	189	220	251	281	312	342	7
8	-23	8	39	68	99	129	160	190	221	252	282	313	343	8
9	-22	9	40	69	100	130	161	191	222	253	283	314	344	9
10	-21	10	41	70	101	131	162	192	223	254	284	315	345	10
11	-20	11	42	71	102	132	163	193	224	255	285	316	346	11
12	-19	12	43	72	103	133	164	194	225	256	286	317	347	12
13	-18	13	44	73	104	134	165	195	226	257	287	318	348	13
14	-17	14	45	74	105	135	166	196	227	258	288	319	349	14
15	-16	15	46	75	106	136	167	197	228	259	289	320	350	15
16	-15	16	47	76	107	137	168	198	229	260	290	321	351	16
17	-14	17	48	77	108	138	169	199	230	261	291	322	352	17
18	-13	18	49	78	109	139	170	200	231	262	292	323	353	18
19	-12	19	50	79	110	140	171	201	232	263	293	324	354	19
20	-11	20	51	80	111	141	172	202	233	264	294	325	355	20
21	-10	21	52	81	112	142	173	203	234	265	295	326	356	21
22	-9	22	53	82	113	143	174	204	235	266	296	327	357	22
23	-8	23	54	83	114	144	175	205	236	267	297	328	358	23
24	-7	24	55	84	115	145	176	206	237	268	298	329	359	24
25	-6	25	56	85	116	146	177	207	238	269	299	330	360	25
26	-5	26	57	86	117	147	178	208	239	270	300	331	361	26
27	-4	27	58	87	118	148	179	209	240	271	301	332	362	27
28	-3	28	59	88	119	149	180	210	241	272	302	333	363	28
29	-2	29	60	89	120	150	181	211	242	273	303	334	364	29
30	-1	30		90	121	151	182	212	243	274	304	335	365	30
31		31		91		152		213	244		305		366	31

Water Velocity and Suspended Solids Measurements by In-situ Instruments in Upper Klamath Lake, Oregon

By Jeffrey W. Gartner, Roy E. Wellman, Tamara M. Wood, and Ralph T. Cheng

Abstract

The U. S. Geological Survey conducted hydrodynamic measurements in Upper Klamath Lake during four summer seasons (approximately mid-June to mid-September) during 2003 to 2006. Measurements included water current profiles made by acoustic Doppler current profilers at a number of fixed locations in the lake during all four years as well as from a moving boat during 2005 and 2006. Measurements of size distribution of suspended material were made at four locations in the lake during 2004-2006. Raw (unfiltered) data are presented as time series of measurements. In addition, water-velocity data have been filtered to remove wind-induced variations with periods less than thirty hours from the measurements. Bar graphs of horizontal and vertical water speed and acoustic backscatter have been generated to discern diurnal variations, especially as they relate to wind patterns over the lake.

Mean speeds of the horizontal currents in the lake range between about 3.5 to 15 cm/s with the higher speeds at the deep locations in the trench on the west side of the lake. Current directions generally conform to the lake's bathymetry contours and the water circulation pattern is usually in a clockwise direction around the lake as established by the prevailing north to northwesterly surface winds in the region. Diurnal patterns in horizontal currents probably relate to diurnal wind patterns with minimum wind speeds near noon and maximum wind speeds near 2100. Diurnal variations in vertical velocities do not appear to be related to wind patterns; they do appear to be related to expected patterns of vertical migration of *Aphanizomenon flos aquae*, (AFA) the predominant species of blue-green algae in the lake. Similarly, diurnal variations in acoustic backscatter, especially near the lake's surface, are probably related to the vertical migration of AFA.

Introduction

Field measurements described in this report were collected from 2003 to 2006 as part of ongoing research by the U.S. Geological Survey (USGS) into the hydrodynamic characteristics of Upper Klamath Lake, Oregon. Upper Klamath Lake has been historically eutrophic and has experienced annual occurrences of large cyanobacterial blooms (primarily *Aphanizomenon flos-aquae,* or AFA) in recent decades. The growth and decomposition of the dense algal blooms frequently cause extreme water quality conditions characterized by high pH (9-10.5) and ammonia concentrations (>0.5 mg/l unionized) and widely variable dissolved oxygen (anoxic to supersaturated) (Wood, 2001; Wood and others, 2006). The lake is the habitat of two endangered species, the Lost River and shortnose suckers.

Purpose and Scope

The purpose of this report is to document the hydrodynamic measurements collected in Upper Klamath Lake by acoustic Doppler current profilers (ADCPs) and by an in-situ laser particle size analyzer during 2003 to 2006. The report describes water velocity measurements by ADCPs made at both fixed stations and from a moving boat. Because these data provide a general, but spatially limited understanding of circulation in Upper Klamath Lake, the water velocity measurements have been used to calibrate and validate a detailed numerical hydrodynamic model that has been implemented to provide quantitative evaluation of impacts of hydrodynamics on water quality in the lake (Cheng and others, 2005, Wood and Cheng, 2006). The ADCP measurements are presented in the form of time series plots of unfiltered and filtered speeds and directions at representative depths (Appendix A) and bar graphs of horizontal and vertical water speeds at representative depths for the 2005 ADCP measurements (Appendices B and C). Some additional analyses were conducted with the 2005 data sets because those measurements included the most complete simultaneous spatial coverage of the lake. In order to facilitate interpretation of original data by other potential users, the data file formats are documented in Appendix D. During 2005 and 2006, numerous measurements of velocity profiles were made by a downward oriented ADCP mounted on a boat. Those data are documented in tabular form. In addition to the ADCP water-velocity data, suspended solids size-distribution and volume-concentration measurements recorded by an in-situ laser particle size analyzer are included in Appendix E. Bar graphs showing diurnal variations of acoustic backscatter intensity, a qualitative surrogate for suspended solids, as recorded by the five ADCPs deployed in 2005 are presented in Appendix F. For comparative purposes, time series of wind speeds and directions are documented in Appendix G and bar graphs showing diurnal variations in wind speeds for 2005 are displayed in Appendix H.

Time series of both unfiltered and filtered ADCP water velocity profile measurements are available online at *http://pubs/usgs.gov/of/2007/1279/data* and software (VPV) to animate the ADCP data can be found at *http://ca.water.usgs.gov/program/sfbay/vpv/*. In addition, field measurements by the in-situ laser particle size analyzer are available at *http://pubs/usgs.gov/of/2007/1279/data*. Software (Gr) to view those data can be found at *http://ca.water.usgs.gov/program/sfbay/gr/*. A program (GetADCPbin.exe) is included in the directory with the field data that allows a user to generate a time series of water direction, speed, and vertical velocity, as well as backscatter in counts and (corrected) dB from a selected bin in an ADCP record. The time series can be plotted using the Gr software. Wind data from Upper Klamath Lake can be found at *http://or.water.usgs.gov/projs_dir/klamath_ltmon/*.

Acknowledgements

The authors gratefully acknowledge the assistance of personnel from the USGS California Water Science Center, the Oregon Water Science Center, and the USGS Biological Resource Discipline Klamath Falls Field Station who participated in various aspects of the field work. This work was partially funded by the U. S. Bureau of Reclamation and the USGS National Research Program.

Field Location and Equipment

Upper Klamath Lake is the largest fresh-water lake in Oregon with an area of about 235 km^2, but a mean depth of only about 2.4 m (fig. 1). The lake trends generally from northwest to southeast. The north end of the lake is dominated by marshes and the lake’s connection to adjoining Agency Lake and the Williamson River. At the south, the lake ends at the Link River Dam and the city of Klamath Falls, Oregon. While the majority of the lake is relatively shallow, on the west side of the lake, a 15-km trench with depths up to about 15 m runs between Bare Island and Eagle Ridge to the north and Sesti Tgawaals Point to the south.

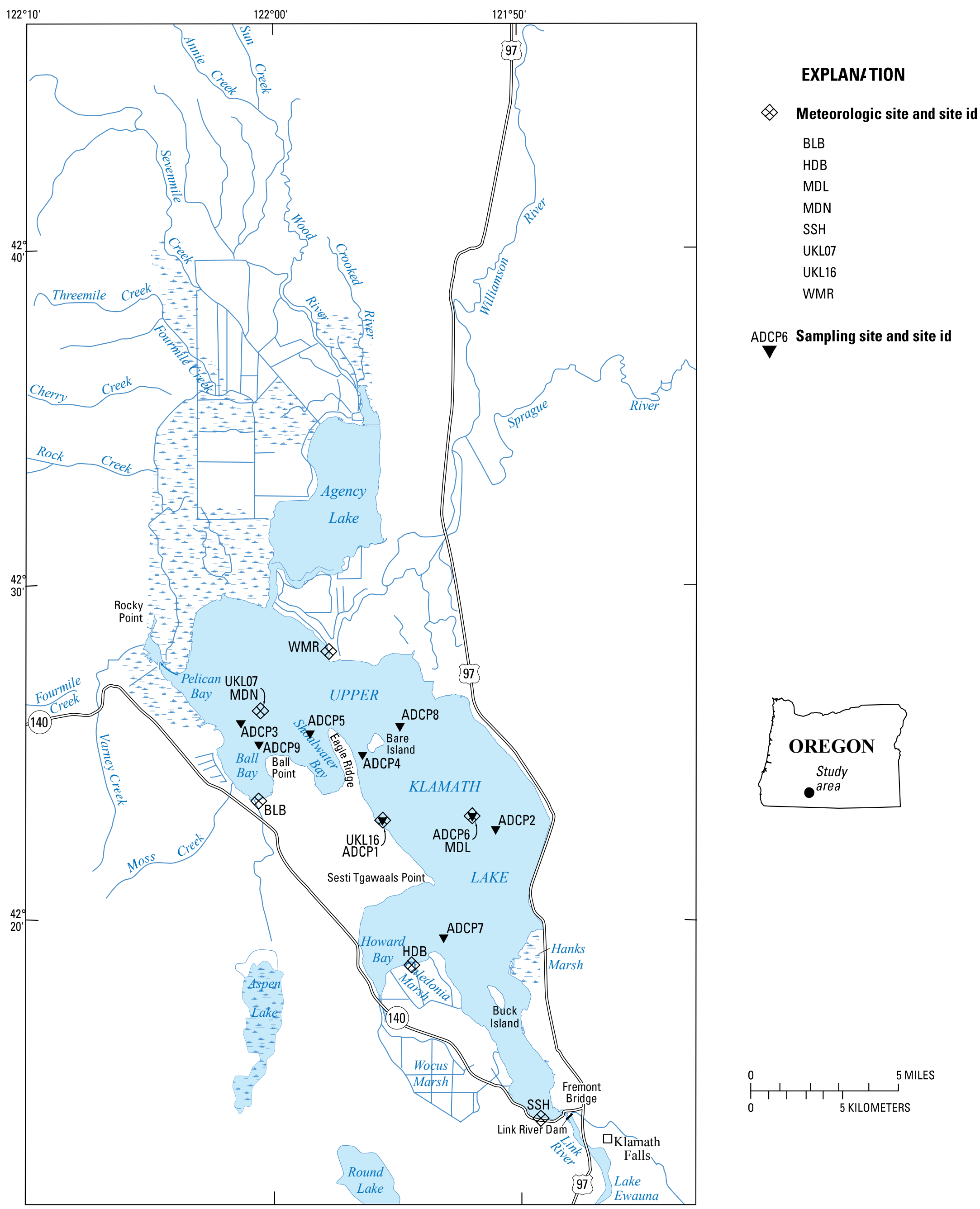

Figure 1. Upper Klamath Lake, Oregon showing locations of ADCPs and meteorological sample stations during 2003-2006 field seasons.

Field Measurement Locations

In order to help define wind-driven circulation and calibrate and validate a numerical hydrodynamic model, current velocity profile data were measured by ADCPs during 16 deployments at nine long-term station locations in the lake during the four field seasons (2003-2006). Station location information is contained in figure 1 and table 1a. Long-term ADCP measurements were made at two locations in the lake during 2003 and 2006, at four locations in 2004, and at five locations in 2005. During the 2006 field season, the ADCP mooring at station 1 (ADCP1C) was hit by a barge at about 1330 on July 5. The ADCP mooring was dragged about 210 m to the north. Although the ADCP mooring was recovered and redeployed on July 18 (ADCP1D), subsequent analysis showed that the data collected between 1400 July 5, 2006 and July 18, 2006 was usable (the ADCP was oriented relatively level during that time). Several different ADCPs, all manufactured by Teledyne RD Instruments, were used during these studies. A 600 kHz WorkHorse (WH) ADCP was used at the deep location in the lake and 1200 kHz WH and BroadBand (BB) ADCPs were used at the shallow locations. All of the ADCPs were self contained units with battery packs and internal memory for data recording.

Table 1a. ADCP deployment location information during 2003, 2004, 2005, and 2006 field seasons in Upper Klamath Lake, Oregon. The last good data bin is variable because the lake level decreases during the summer. The water depth is the depth at the beginning of the deployment.

STATION	ADCP TYPE	START DATE	STOP DATE	LATITUDE	LONGITUDE	WATER DEPTH	BIN 1 LOCATION	LAST BIN
ADCP8A	1200 kHz WH	7/2/03	7/29/03	42-25-54N	121-54-55W	2.9 m	87 cm	9-8
ADCP8B	1200 kHz WH	7/29/03	9/23/03	42-25-54N	121-54-55W	2.5 m	87 cm	8-6
ADCP4A	1200 kHz WH	7/2/03	7/29/03	42-25-03N	121-56-27W	9.4 m	87 cm	40-38
ADCP4B	1200 kHz WH	7/29/03	9/23/03	42-25-03N	121-56-27W	9.1 m	87 cm	39-37
ADCP2A	1200 kHz WH	6/16/04	8/5/04	42-22-49N	121-51-02W	3.5 m	89 cm	11-9
ADCP3A	1200 kHz WH	8/5/04	9/15/04	42-26-00N	122-01-23W	3.5 m	89 cm	10-8
ADCP1A	600 kHz WH	6/16/04	8/5/04	42-23-05N	121-55-39W	13.1 m	123 cm	24-23
ADCP4C	600 kHz WH	8/5/04	9/15/04	42-25-04N	121-56-30W	9.5 m	123 cm	15-14
ADCP1B	600 kHz WH	6/21/05	9/12/05	42-23-06N	121-55-45W	14.2 m	126 cm	24-23
ADCP3B	1200 kHz WH	6/21/05	9/12/05	42-26-00N	122-01-23W	4.6 m	91 cm	13-9
ADCP5A	1200 kHz BB	6/21/05	9/12/05	42-25-41 N	121-58-35W	5.3 m	156 cm	15-11
ADCP6A	1200 kHz BB	6/21/05	9/12/05	42-23-12N	121-51-59W	4.4 m	121 cm	12-8
ADCP7A	1200 kHz BB	6/21/05	9/12/05	42-19-35N	121-53-10W	5.3 m	141 cm	13-9
ADCP1C	600 kHz WH	5/24/06	7/18/06	42-23-06N	121-55-33W	12.0 m	126 cm	21-18
ADCP1D	600 kHz WH	7/18/06	9/25/06	42-23-05N	121-55-49W	13.0 m	126 cm	22-21
ADCP9A	1200 kHz WH	5/24/06	9/25/06	42-25.22N	122-00-39W	5.0 m	94 cm	15-11

In addition to the in-situ measurements, short-duration water velocity measurements were also made with a vessel-mounted 1200 kHz ADCP at 29 locations in the lake in 2005. Velocity profile measurements were computed at 24 additional locations along discharge transects made between Eagle Point and Bare Island. In 2006, short-duration velocity measurements were made at 21 locations in the lake and 8 additional measurements were calculated from discharge transects collected near Sesti Tgawaals Point. Vessel positions for the measurements were determined using a Global Positioning

System (GPS). Those synoptic measurements were conducted to determine water velocity information in areas of interest not previously measured by long-term deployments. Locations of those measurements are shown in table 1b and 1c.

Table 1b. Location information for boat collected ADCP velocity profiles during 2005 field season.

LOCATION NUMBER	MM/DD/YY	HH:MM:SS	MID-POINT LATITUDE	MID-POINT LONGITUDE	LOWEST BIN DEPTH	AVERAGE DEPTH
UKL05bareQ1.1	8/25/2005	19:06:21	42-25-07N	121-56-18W	3.93	4.44
UKL05bareQ1.2	8/25/2005	19:09:36	42-25-06N	121-56-22W	3.93	5.31
UKL05bareQ1.3	8/25/2005	19:12:54	42-25-04N	121-56-27W	5.93	7.99
UKL05bareQ1.4	8/25/2005	19:16:15	42-25-02N	121-56-32W	7.93	9.10
UKL05bareQ1.5	8/25/2005	19:19:36	42-25-01N	121-56-37W	6.93	8.11
UKL05bareQ1.6	8/25/2005	19:22:54	42-24-59N	121-56-42W	5.93	7.05
UKL05bareQ1.7	8/25/2005	19:26:13	42-24-58N	121-56-46W	4.93	5.77
UKL05bareQ1.8	8/25/2005	19:29:30	42-24-56N	121-56-50W	2.93	3.00
UKL05bareQ2.1	8/26/2005	10:08:17	42-24-55N	121-56-49W	5.93	7.16
UKL05bareQ2.2	8/26/2005	10:11:37	42-24-56N	121-56-45W	6.93	8.21
UKL05bareQ2.3	8/26/2005	10:14:57	42-24-58N	121-56-40W	7.43	8.95
UKL05bareQ2.4	8/26/2005	10:18:21	42-24-59N	121-56-36W	7.43	8.79
UKL05bareQ2.5	8/26/2005	10:21:38	42-25-00N	121-56-32W	6.93	6.78
UKL05bareQ2.6	8/26/2005	10:24:56	42-25-02N	121-56-28W	4.93	4.82
UKL05bareQ2.7	8/26/2005	10:28:13	42-25-04N	121-56-24W	3.43	4.24
UKL05bareQ2.8	8/26/2005	10:31:28	42-25-06N	121-56-20W	3.93	3.74
UKL05bareQ3.1	8/26/2005	15:27:09	42-24-56N	121-56-48W	4.93	6.72
UKL05bareQ3.2	8/26/2005	15:31:18	42-24-58N	121-56-44W	6.43	7.67
UKL05bareQ3.3	8/26/2005	15:35:27	42-25-00N	121-56-39W	6.93	8.69
UKL05bareQ3.4	8/26/2005	15:39:38	42-25-02N	121-56-35W	7.93	8.86
UKL05bareQ3.5	8/26/2005	15:43:47	42-25-04N	121-56-31W	7.43	7.48
UKL05bareQ3.6	8/26/2005	15:47:54	42-25-05N	121-56-27W	5.43	5.44
UKL05bareQ3.7	8/26/2005	15:52:01	42-25-06N	121-56-24W	3.93	4.99
UKL05bareQ3.8	8/26/2005	15:56:08	42-25-07N	121-56-20W	4.43	4.97
UKL05S001.1	8/25/2005	12:38:59	42-19-02N	121-51-10W	1.87	2.04
UKL05S002.1	8/25/2005	13:39:34	42-20-46N	121-51-21W	2.37	2.48
UKL05S003.1	8/25/2005	14:08:15	42-21-16N	121-51-22W	1.72	1.91
UKL05S004.1	8/25/2005	14:33:06	42-21-49N	121-51-18W	2.27	2.44
UKL05S005.1	8/25/2005	14:49:21	42-22-31N	121-51-19W	3.22	3.35
UKL05S006.1	8/25/2005	15:09:49	42-23-18N	121-51-27W	3.37	3.50
UKL05S007.1	8/25/2005	15:38:45	42-22-48N	121-51-15W	3.27	3.40
UKL05S008.1	8/25/2005	15:56:14	42-22-22N	121-50-35W	2.52	2.76
UKL05S010.1	8/25/2005	16:52:14	42-21-11N	121-51-56W	2.02	2.21
UKL05S011.1	8/25/2005	17:06:46	42-21-42N	121-52-40W	2.72	2.88
UKL05S012.1	8/25/2005	17:22:51	42-22-07N	121-53-20W	4.17	4.37

LOCATION NUMBER	MM/DD/YY	HH:MM:SS	MID-POINT LATITUDE	MID-POINT LONGITUDE	LOWEST BIN DEPTH	AVERAGE DEPTH
UKL05S013.1	8/25/2005	17:51:50	42-22-33N	121-53-53W	3.71	4.22
UKL05S014.1	8/25/2005	18:13:01	42-23-03N	121-54-29W	2.51	2.95
UKL05S016.1	8/26/2005	11:50:39	42-26-43N	121-54-09W	1.82	1.98
UKL05S017.1	8/26/2005	12:08:11	42-26-05N	121-54-20W	2.07	2.23
UKL05S018.1	8/26/2005	12:30:22	42-25-36N	121-54-34W	2.22	2.34
UKL05S019.1	8/26/2005	12:46:57	42-24-59N	121-54-56W	2.22	2.37
UKL05S020.1	8/26/2005	13:05:29	42-24-28N	121-55-11W	2.37	2.51
UKL05S021.1	8/26/2005	13:32:37	42-23-57N	121-55-26W	2.47	2.66
UKL05S022.1	8/26/2005	14:22:18	42-26-03N	121-57-52W	8.93	10.39
UKL05S023.1	8/26/2005	14:40:12	42-26-31N	121-57-41W	1.82	1.97
UKL05S024.1	8/26/2005	14:51:10	42-27-04N	121-57-27W	1.47	1.67
UKL05S025.1	8/26/2005	14:55:36	42-27-04N	121-57-28W	1.47	1.67
UKL05S026.1	8/26/2005	16:51:49	42-23-54N	121-56-18W	11.22	11.91
UKL05S027.1	8/26/2005	17:11:20	42-22-16N	121-54-46W	4.82	6.13
UKL05S028.1	8/26/2005	17:29:03	42-21-35N	121-53-40W	3.47	3.77

Table 1c. Location information for boat collected ADCP velocity profiles during 2006 field season.

LOCATION NUMBER	MM/DD/YY	HH:MM:SS	MID-POINT LATITUDE	MID_POINT LONGITUDE	LOWEST BIN DEPTH	AVERAGE DEPTH
UKL06s000.1	7/18/2006	17:39:48	42-23-09N	121-51-58W	3.69	3.85
UKL06s001.1	7/19/2006	12:01:02	42-21-25N	121-53-09W	5.40	6.19
UKL06s002.1	7/19/2006	15:35:43	42-19-24N	121-53-37W	1.65	2.15
UKL06s003.1	7/19/2006	15:52:03	42-19-22N	121-53-36W	2.04	2.21
UKL06s004.1	7/19/2006	16:19:54	42-18-28N	121-50-41W	1.89	2.10
UKL06s005.1	7/19/2006	16:53:07	42-17-16N	121-50-44W	2.24	2.48
UKL06s006.1	7/19/2006	17:05:34	42-17-16N	121-50-43W	2.24	2.46
UKL06s007.1	7/20/2006	10:37:17	42-16-59N	121-50-41W	2.53	2.87
UKL06s008.1	7/20/2006	11:15:07	42-16-33N	121-50-28W	2.43	2.75
UKL06s009.1	7/20/2006	11:55:27	42-16-26N	121-50-59W	2.53	2.88
UKL06s010.1	7/20/2006	12:14:58	42-16-26N	121-50-51W	2.23	2.49
UKL06s011.1	7/20/2006	12:30:27	42-16-26N	121-50-51W	2.23	2.48
UKL06s012.1	7/20/2006	13:08:10	42-16-26N	121-50-43W	2.33	2.57
UKL06s013.1	7/20/2006	13:31:03	42-16-29N	121-50-18W	2.43	2.73
UKL06s014.1	7/20/2006	13:35:12	42-16-30N	121-50-18W	2.43	2.75
UKL06s015.1	7/20/2006	13:47:21	42-16-33N	121-50-09W	2.33	2.67
UKL06s016.1	7/20/2006	14:02:20	42-16-36N	121-50-02W	2.23	2.56
UKL06s017.1	7/20/2006	14:33:48	42-16-09N	121-49-51W	2.13	2.46
UKL06s018.1	7/20/2006	15:21:53	42-15-49N	121-50-33W	2.93	3.27
UKL06s019.1	7/20/2006	15:55:35	42-17-46N	121-52-28W	5.15	6.07
UKL06s020.1	7/20/2006	16:11:11	42-17-55N	121-52-00W	2.13	2.36
UKL06s021.1	7/20/2006	16:26:44	42-18-02N	121-51-40W	2.13	2.39

UKL06s022.1	7/20/2006	16:50:08	42-21-18N	121-53-33W	3.40	4.01
UKL06s022.2	7/20/2006	16:54:52	42-21-17N	121-53-27W	3.15	3.87
UKL06s022.3	7/20/2006	16:59:37	42-21-17N	121-53-23W	3.4	4.00
UKL06s022.4	7/20/2006	17:04:24	42-21-18N	121-53-18W	3.90	4.73
UKL06s022.5	7/20/2006	17:09:13	42-21-20N	121-53-13W	4.90	5.86
UKL06s022.6	7/20/2006	17:14:02	42-21-24N	121-53-08W	5.15	5.93
UKL06s022.7	7/20/2006	17:18:50	42-21-26N	121-53-02W	4.65	5.29

Characteristics of the suspended solids in Upper Klamath Lake measured by a Laser In Situ Scattering and Transmissometry (LISST) instrument, including mean size distribution, volume concentration, and percent transmission are documented in this report. LISST data were collected at shallow water sites ADCP2 and ADCP3 in 2004, near ADCP6 in 2005, and near ADCP9 in 2006.

Acoustic Doppler Current Profiler (ADCP)

An ADCP determines water velocity profiles by transmitting sound pulses at a fixed frequency and measuring the frequency (or phase) shift of acoustic echoes reflected back from scatterers (organics and sediment) in the water (Simpson, 2001). Doppler shifted echoes are then converted to along (acoustic) beam velocity components. Finally, the ADCP transforms the along beam velocities to north/south, east/west, and vertical velocity components using trigonometric relations. Velocity profiles are determined by range gating echoes so that velocities are determined at preset intervals (bins) along the acoustic path. When the instrument is oriented facing down and measurements are made from a moving vessel, relative instrument position is determined using separate bottom track acoustic pings or GPS position information.

There are several modes of ADCP operation available; selection depends upon the water depth and other considerations. An evaluation and detailed discussion of the ADCP modes can be found in RD Instruments, Inc (1996) and RD Instruments, Inc (1997). Typically, the highest sampling rate and smallest usable bin-size consistent with instrument frequency and accuracy requirements are chosen to give the best possible spatial resolution of velocity distribution in the vertical direction.

During these studies, all bottom-mounted ADCPs were programmed to sample using Water Mode 1 with a 25 cm (WH ADCPs) or 35 cm (BB ADCPs) blank distance (figs. 2 and 3). A blank distance (in which no usable data are available) is required because these instruments use the same transducers to both transmit and receive the acoustic signals. A short time interval is necessary for acoustic ringing to dissipate before the transducers can receive usable information. Also, because there is flow distortion near the transducers, some small distance is required before reliable velocity data can be determined (Gartner and Ganju, 2002). The location of the center of bin 1 for each ADCP profile depends on the mooring platform design and ADCP setup commands. The 600 kHz ADCP was usually programmed with a 50 cm bin size, thus the center of the first bin was located at about 125 cm above bed; the 1,200 kHz ADCPs were programmed with 20 or 25 cm bin sizes. The center of the first bin in the 1,200 kHz data sets varied from about 87-156 cm depending on instrument and mooring design. (See table 1a for the exact distances from the lake bottom to the center of the first bin for each ADCP data set.) Sufficient individual acoustic pings were averaged to reduce the theoretical standard deviation of the recorded horizontal velocities to be less than 1 cm/s for each measurement. Theoretical standard deviations of vertical velocities are better; they were approximately 0.3 cm/s. Water velocity measurements were made at thirty-minute intervals.

Figure 2. 600 kHz WorkHorse model acoustic Doppler current profiler shown on bottom mooring platform as deployed in Upper Klamath Lake. Onboard data measurements are being downloaded to laptop computer via cable shown in bottom right of photograph.

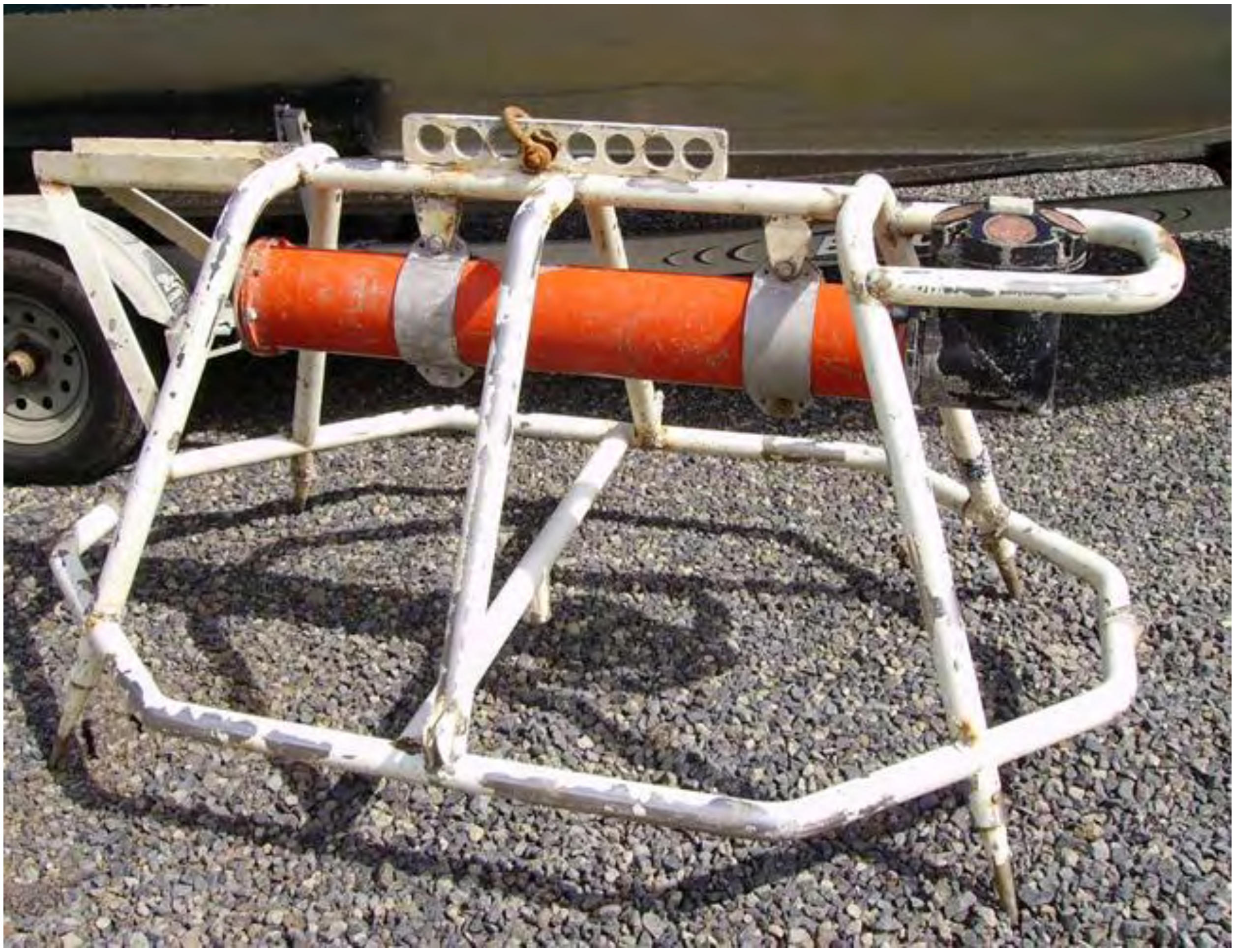

Figure 3. A 1200 kHz Broadband model acoustic Doppler current profiler on bottom mooring platform readied for deployment in Upper Klamath Lake in 2005.

Laser In-situ Scattering and Transmissometry (LISST)

There is a class of instrument that uses laser diffraction for measurement of particle size distribution (Hildebrand and Row, 1995); McCave and others, 1986). In the early 1990s, a completely in-situ version of a laser diffraction instrument (Agrawal and Pottsmith, 1994) was developed and tested. A commercial counterpart, the LISST-100, has been introduced by Sequoia Scientific Inc. (Pottsmith and Bhogal, 1995; Agrawal and others, 1996). Instrument theory (Agrawal and Pottsmith, 1994), operation (Agrawal and others, 1991; Agrawal and Pottsmith, 1993), and testing (Pottsmith and Bhogal, 1995; Agrawal and others, 1996; Traykovski and others, 1999; Gartner and others, 2001) are well documented and will not be discussed here.

The LISST-100B (the version deployed in Upper Klamath Lake) measures forward scattered laser light intensity distribution through a 5 cm laser path length utilizing a series of 32 annular ring-detectors to estimate particle size distribution in the range of 1.25-250 μm. Data acquisition and analysis software supplied by the manufacturer is used to convert measurements to particle size distribution in 32 logarithmically spaced size classes. Particle volume distribution is estimated by determining the volume in each size class utilizing a known calibration value. Conversion from volume distribution to mass concentration is possible if characteristic density of the suspended material is known and relatively constant. In this report, concentration of suspended material is presented as volume concentration since density of suspended material in Upper Klamath Lake is presently unknown and is assumed to vary with depth, time, and composition. The LISST instrument also measures optical transmission, water temperature, and water pressure.

The LISST was moored at about 30 cm above bed in 2004 and at about 120 cm above bed in 2005 and 2006. The LISST was programmed to average 99 readings (45 readings in 2006) to calculate a mean data set once every 15 minutes. The time required for each recorded reading took about 25 seconds when 99 readings were averaged. Only short records are usable in 2004 because of biological fouling of the optical lenses. In 2005 and 2006 the LISST was moored on its own array that was recovered and redeployed on a weekly cycle for lens cleaning. (Appendix E contains a list of dates and times that the optical lenses on the LISST were cleaned during the 2005 and 2006 deployments.) In spite of lens cleaning, there are still some periods of signal degradation that are especially severe during periods of high algal bloom. Only a short data set is available in 2006 because of biological fouling and subsequent instrument failure.

Data Presentation

Water currents in the lake are displayed as time series plots of unfiltered water speed and direction measurements. Plots of water velocity from near-bottom, mid-water, and near surface ADCP bins are shown as representative. Velocity measurements have been low-pass-filtered; similar to the unfiltered velocity measurements, those data are also presented as time-series plots of filtered water speed and direction from the same near-bottom, mid-water, and near-surface bins. The near-surface bin displayed in the time-series plot is the highest good measurement bin at the end of the deployment period. Additionally, short-duration velocity profile measurements made by vessel mounted ADCP in 2005 and 2006 are documented. Those data are presented as mean water speed and direction for the entire profile, and at near-bottom, mid water, and near-surface sections of the water column. Bar graphs of ADCP data from 2005 at the five, long-term stations are included in order to show diurnal variations in horizontal and vertical water currents. Time series plots of the LISST data and bar graphs of the ADCP backscatter intensity data from 2005 are provided. Wind data from 2003-2006 are presented and bar graphs of wind data from 2005 are shown to show diurnal variations in wind. For consistency, all references to time in this report are local time (Pacific Daylight Savings Time).

Low-Pass Filtered Data

Applying a low-pass filter to the data selectively removes frequency signals that are greater than a specified cutoff value. In the analysis of data from wind-driven waters such as Upper Klamath Lake, the objective is to remove signals in the data with periods less than 30 hours (most importantly, the diurnal wind effects). The data in this report were filtered using a discrete Fourier transform filter similar to that described by Walters and Heston (1982). A cosine taper was applied between a stop frequency of 30 hours and a pass frequency of 40 hours to reduce "ringing" in the results (Burau and others, 1993). The filtered ADCP records provided online contain the same number of bins of data as do the corresponding unfiltered records. In both cases, as the deployment progresses, some data from near-surface bins become unreliable because of decreasing water level in the lake. (See the column labeled “last bin” in table 1a which displays the last good data bin at the start and end of each ADCP measurement.)

Bar Graphs to Display Timing of Diurnal Patterns

Diurnal patterns and the timing of minimum and maximum horizontal and vertical water velocities, wind speed, and acoustic backscatter are displayed in bar graphs. Bar graphs were created from data sets by summing measurements at each recorded time of day (15- or 30-minute intervals) over the length of the record and then dividing by the number of valid measurements. Except for wind, bar graphs were created for near-surface and near bottom positions in order to examine spatial and vertical variations in the daily timing of maxima and minima in the lake.

Converting ADCP Backscatter to Backscatter Intensity in Decibels

As use of ADCPs has become more widespread, so have attempts to characterize suspended material from acoustic backscatter intensity measurements made by those acoustic instruments used to measure water velocity (e.g. Thevenot and others, 1992; Reichel and Nachtnebel, 1994). In addition to being less susceptible to biological fouling than are optical sensors, commercially available ADCPs may provide non-intrusive estimates of suspended solids concentration (SSC) profiles concurrent with measurements of velocity profiles using the same instrument. However, the process of converting backscatter intensity to mass concentration is not straightforward. Among other things, complex acoustic transmission losses from beam spreading and attenuation from water and suspended solids must be accounted for correctly. Transmission losses depend on multiple factors including the characteristics and quantity of suspended material, the salinity, temperature, and pressure of water, and the instrument power, transducer size, and frequency. Gartner (2004) provides a discussion of the theoretical background of the technique, including inherent limitations using single frequency instruments, appropriate frequency for a given particle size distribution, and corrections for attenuation from suspended materials, and non-spherical spreading in the transducer near field.

In this report, recorded ADCP backscatter is converted to backscatter intensity (units of dB) by correcting for transmission losses including acoustic spreading and absorption from water; however, no attempt is made to correct for attenuation from suspended materials or to convert the corrected backscatter intensity to SSC. There are several reasons for not compensating for suspended material including lack of sufficient calibration samples to define the vertical variations in the ratio of inorganic to organic material or actual mass concentration, the large size of the organic material (AFA) relative to acoustic frequency, and the lack of knowledge regarding composition and in-situ density of suspended materials. Therefore, in this report, spatial and temporal variations of suspended material are limited to a qualitative analysis of the corrected backscatter intensity only.

Discussion

ADCP Velocity Measurements

A preliminary analysis of the 2003 and 2004 ADCP measurements can be found in Wood and others (2006). They found that during periods of prevailing (west-northwesterly) wind conditions, currents in the trench west of Bare Island at site ADCP4 flowed generally north (≈350 degrees) whereas currents at ADCP8, the more shallow site to the east of Bare Island, were generally aligned to the southeast (≈120-150 degrees). (All wind and current directions are referenced to true north. By convention, wind directions are given as direction the wind is blowing from and current directions refer to the direction the currents are flowing toward.) The generally clockwise circulation pattern established in the lake under prevailing wind conditions seen in the 2003-2004 data is further confirmed by the velocity profile measurements by ADCP in 2005 and 2006. Time series of ADCP data from near-surface, mid-depth, and near-bottom bins collected from 2003-2006 can be found in Appendix A and a summary of mean speeds and predominant directions near surface and near bottom are tabulated in table 2. As in 2003 and 2004, currents in the trench on the west side of the lake (ADCP1) were aligned with the bathymetry (generally north or northwest, ≈320-330 degrees), as were the currents at ADCP3. Predominant currents at ADCP3, which was located at the end of a segment of the trench that runs across Ball Point and turns north at the entrance to Ball Bay, were about 340-350 degrees in 2005 but currents at ADCP9 which was located about 1100 m east and 800 m south of ADCP3, in open water north of the trench, were about 280-310 degrees in 2006. Prevailing current directions at ADCP5 aligned with a segment of the trench that runs across the entrance to Shoalwater Bay, consistent with the conceptual model of wind-driven current patterns in the lake shown in Wood and others (2006). Currents at ADCP5 flowed southwest between about 230 to 250 degrees. Currents in the shallow east side of the lake at ADCP6 were generally south to southeast (≈150-160 degrees) and currents at ADCP7 were generally northeast at about 30-40 degrees. ADCP7 was located at the southern most end of the trench which trends to the northeast at that location.

Summaries of the results of vessel-mounted ADCP measurements in 2005 and 2006 are tabulated in tables 3a and 3b.

Table 2. Mean current speeds and directions near surface and near bottom as measured by ADCP. Near-bottom data are not necessarily from bin 1 but vary from about 1.6-1.7 m above bed based on ADCP setup and transducer height. Near surface data are from the last "good" data bin at end of deployment (lake levels dropped about 1.1-1.2 cm/day during deployments).

STATION NUMBER	MEAN SPEED (SURFACE)	MEAN SPEED (BOTTOM)	FLOW DIRECTION (SURFACE)	FLOW DIRECTION (BOTTOM)	WATER DEPTH
ADCP8A	9.9 cm/s(bin 8)	9.1 cm/s (bin 5)	130-140 deg. T	130-140 deg. T	2.9 m
ADCP8B	9.0 cm/s bin 6)	8.7 cm/s (bin 5)	130-140 deg. T	130-140 deg. T	2.5 m
ADCP4A	13.8 cm/s (bin 37)	8.9 cm/s (bin 5)	10 deg. T	350 deg. T	9.4 m
ADCP4B	11.0 cm/s (bin 36)	8.7 cm/s (bin 5)	10 deg. T	360 deg. T	9.1 m
ADCP2A	3.7 cm/s (bin 9)	3.5 cm/s (bin 4)	160-170 deg. T	60-70 & 190 deg. T	3.5 m
ADCP3A	5.7 cm/s (bin 8)	5.8 cm/s (bin 4)	350 deg. T	340-350 deg. T	3.5 m
ADCP1A	10.6 cm/s (bin 22)	9.5 cm/s (bin 2)	320-330 deg. T	330 deg. T	13.1 m
ADCP4C	13.0 cm/s (bin 13)	9.6 cm/s (bin 2)	10-20 deg. T	360-10 deg. T	9.5 m
ADCP1B	10.3 cm/s (bin 23)	9.7 cm/s (bin 2)	320 deg. T	320 deg. T	14.2 m
ADCP3B	5.2 cm/s (bin 9)	5.4 cm/s (bin 4)	340-350 deg. T	340 deg. T	4.6 m
ADCP5A	7.9 cm/s (bin 11)	6.2 cm/s (bin 1)	230-240 deg. T	240-250 deg. T	5.3 m
ADCP6A	3.9 cm/s (bin 8)	3.3 cm/s (bin 3)	150-160 deg. T	150 deg. T	4.4 m
ADCP7A	8.5 cm/s (bin 9)	9.5 cm/s (bin 2)	30-40 deg. T	30 deg. T	5.3 m
ADCP1C	10.0 cm/s (bin 18)	10.7 cm/s (bin 2)	320-330 deg. T	320-330 deg. T	12.0 m
ADCP1D	13.3 cm/s (bin 22)	11.3 cm/s (bin 2)	320-330 deg. T	330 deg. T	13.0 m
ADCP9A	4.6 cm/s (bin 11)	4.5 cm/s (bin 4)	280-290 deg. T	290-310 deg. T	5.0 m

Table 3a. Summary results of measurements by boat mounted ADCP during 2005 field season.

	ENSEMBLE		ABOVE 0.2 DEPTH		BELOW 0.8 DEPTH		0.4-0.6 DEPTH		AVERAGE
LOCATION NUMBER	SPEED (CM/S)	DIRECTION DEG. TRUE	SPEED (CM/S)	DIRECTION DEG. TRUE	SPEED (CM/S)	DIRECTION DEG. TRUE	SPEED (CM/S)	DIRECTION DEG. TRUE	DEPTH (M)
UKL05bareQ1.1	1.19	154	3.49	207	1.22	99	1.17	133	4.44
UKL05bareQ1.2	0.92	18	3.48	219	nd	nd	2.05	32	5.31
UKL05bareQ1.3	1.68	348	2.29	234	nd	nd	2.68	358	7.99
UKL05bareQ1.4	1.67	335	2.18	264	0.80	184	3.04	353	9.10
UKL05bareQ1.5	1.34	253	3.01	227	2.19	207	0.72	335	8.11
UKL05bareQ1.6	1.97	215	3.47	227	2.70	179	1.04	235	7.05
UKL05bareQ1.7	2.62	200	3.12	230	4.25	160	2.34	213	5.77
UKL05bareQ1.8	1.92	191	nd	nd	2.17	161	2.33	211	3.00
UKL05bareQ2.1	2.52	158	5.91	165	1.48	118	1.56	174	7.16
UKL05bareQ2.2	2.93	169	6.30	158	2.24	151	2.41	199	8.21
UKL05bareQ2.3	4.03	183	5.65	160	2.67	163	4.69	202	8.95
UKL05bareQ2.4	5.58	187	7.56	160	3.00	195	6.32	199	8.79
UKL05bareQ2.5	5.96	184	8.79	167	4.33	217	6.5	180	6.78
UKL05bareQ2.6	2.75	196	4.42	175	2.81	221	2.48	185	4.82
UKL05bareQ2.7	2.42	260	1.92	231	4.08	281	2.26	252	4.24
UKL05bareQ2.8	3.41	303	2.05	313	4.35	304	2.95	298	3.74
UKL05bareQ3.1	4.43	157	2.88	146	nd	nd	4.72	150	6.72
UKL05bareQ3.2	6.55	159	5.97	140	6.46	152	5.95	166	7.67
UKL05bareQ3.3	7.17	157	7.41	145	6.05	149	7.23	162	8.69
UKL05bareQ3.4	7.22	163	5.86	145	6.01	164	7.95	170	8.86
UKL05bareQ3.5	6.26	170	3.28	159	4.99	159	7.83	178	7.48
UKL05bareQ3.6	6.13	166	3.26	140	4.44	166	7.92	170	5.44
UKL05bareQ3.7	4.16	151	2.64	127	4.40	163	4.43	155	4.99
UKL05bareQ3.8	2.94	139	1.53	79	3.63	150	2.74	139	4.97
UKL05S001.1	4.10	200	11.41	205	1.45	168	3.31	200	2.04
UKL05S002.1	3.93	135	5.31	186	3.32	108	5.08	128	2.48
UKL05S003.1	2.94	128	4.34	188	3.62	93	3.26	131	1.91
UKL05S004.1	4.28	83	2.37	142	3.75	69	5.32	78	2.44
UKL05S005.1	5.43	67	1.79	22	5.01	57	7.14	70	3.35
UKL05S006.1	3.77	42	4.58	357	3.54	47	4.15	51	3.50
UKL05S007.1	4.69	64	1.36	358	4.24	53	5.98	68	3.40
UKL05S008.1	4.62	68	3.14	79	4.32	60	5.12	67	2.76
UKL05S010.1	2.65	107	4.23	284	3.45	105	4.56	106	2.21
UKL05S011.1	3.28	49	4.14	269	2.67	38	6.32	66	2.88
UKL05S012.1	3.62	70	1.93	2	2.42	114	5.22	65	4.37
UKL05S013.1	3.63	124	3.36	37	3.11	134	4.63	136	4.22
UKL05S014.1	3.26	157	2.86	258	3.83	131	4.46	157	2.95

	ENSEMBLE		ABOVE 0.2 DEPTH		BELOW 0.8 DEPTH		0.4-0.6 DEPTH		AVERAGE
LOCATION NUMBER	SPEED (CM/S)	DIRECTION DEG. TRUE	SPEED (CM/S)	DIRECTION DEG. TRUE	SPEED (CM/S)	DIRECTION DEG. TRUE	SPEED (CM/S)	DIRECTION DEG. TRUE	DEPTH (M)
UKL05S016.1	5.14	284	8.3	285	2.17	241	6.20	289	1.98
UKL05S017.1	1.77	292	3.93	285	0.65	251	1.82	306	2.23
UKL05S018.1	1.58	297	2.95	314	1.52	245	1.38	314	2.34
UKL05S019.1	0.58	130	6.02	259	2.80	91	0.96	95	2.37
UKL05S020.1	0.46	83	5.15	272	1.43	101	1.91	79	2.51
UKL05S021.1	0.39	275	5.66	280	2.09	113	0.23	75	2.66
UKL05S022.1	3.61	83	5.97	60	1.52	67	3.49	93	10.39
UKL05S023.1	1.15	209	6.89	296	4.01	137	1.47	230	1.97
UKL05S024.1	3.43	306	nd	nd	3.29	79	4.23	294	1.67
UKL05S025.1	3.28	282	nd	nd	2.24	174	3.76	281	1.67
UKL05S026.1	6.84	162	4.74	157	5.45	153	8.67	164	11.91
UKL05S027.1	5.92	129	5.46	120	5.02	125	6.05	130	6.13
UKL05S028.1	4.73	151	5.02	99	3.73	174	7.10	169	3.77

nd = No data available

Table 3b. Summary results of measurements by boat mounted ADCP during 2006 field season.

LOCATION NUMBER	ENSEMBLE SPEED (CM/S)	ENSEMBLE DIRECTION DEG. TRUE	ABOVE 0.2 DEPTH SPEED (CM/S)	ABOVE 0.2 DEPTH DIRECTION DEG. TRUE	BELOW 0.8 DEPTH SPEED (CM/S)	BELOW 0.8 DEPTH DIRECTION DEG. TRUE	0.4-0.6 DEPTH SPEED (CM/S)	0.4-0.6 DEPTH DIRECTION DEG. TRUE	AVERAGE DEPTH (M)
UKL06s000.1	2.36	112	10.36	186	3.60	47	3.80	64	3.85
UKL06s001.1	6.92	348	9.10	360	6.52	332	6.05	350	6.19
UKL06s002.1	5.08	315	nd	nd	3.49	333	6.03	322	2.15
UKL06s003.1	3.49	300	7.64	228	3.37	339	4.45	316	2.21
UKL06s004.1	2.68	178	11.49	185	1.33	8	2.40	169	2.10
UKL06s005.1	2.01	181	10.59	204	3.82	10	2.90	151	2.48
UKL06s006.1	1.53	203	9.78	204	3.54	358	2.03	150	2.46
UKL06s007.1	4.78	237	8.25	219	2.41	281	4.92	239	2.87
UKL06s008.1	5.34	209	8.16	220	3.37	182	5.32	208	2.75
UKL06s009.1	2.11	184	7.85	169	3.34	284	1.60	158	2.88
UKL06s010.1	3.47	193	11.52	167	3.36	294	2.96	191	2.49
UKL06s011.1	4.27	199	12.41	166	4.30	293	4.37	201	2.48
UKL06s012.1	7.20	193	12.35	166	3.76	238	8.03	194	2.57
UKL06s013.1	2.67	293	5.99	243	1.43	323	3.32	328	2.73
UKL06s014.1	2.07	287	5.01	241	1.04	320	2.63	331	2.75
UKL06s015.1	2.93	303	4.35	227	3.86	339	3.51	307	2.67
UKL06s016.1	2.50	342	1.70	177	3.19	346	3.96	343	2.56
UKL06s017.1	1.91	345	1.62	171	4.01	343	1.90	345	2.46
UKL06s018.1	1.48	121	8.00	180	5.34	13	1.45	120	3.27
UKL06s019.1	4.25	7	4.28	200	7.70	1	5.77	6	6.07
UKL06s020.1	2.93	195	9.3	245	2.33	158	2.96	175	2.36
UKL06s021.1	2.22	203	6.07	237	2.04	174	1.82	204	2.39
UKL06s022.1	3.02	106	4.12	130	4.47	6	5.03	115	4.01
UKL06s022.2	3.01	118	3.35	197	2.86	36	5.7	117	3.87
UKL06s022.3	1.91	106	2.57	246	3.89	42	4.07	120	4
UKL06s022.4	2.03	109	2.67	240	4.2	93	3.07	127	4.73
UKL06s022.5	1.77	54	2.45	294	3.15	65	2.18	118	5.86
UKL06s022.6	1.13	15	2.98	280	2.63	322	2.46	120	5.93
UKL06s022.7	3.11	359	2.27	287	4.44	334	2.54	41	5.29
UKL06s022.8	4.12	359	3.83	234	4.52	340	5.17	16	4.67

nd = No data available

From examination of time series of unfiltered current speeds and directions measured by ADCPs (Appendix A) it is apparent that there are significant diurnal patterns. As an example, one week of measurements near mid-depth at site ADCP1 are shown in figure 4. However, further analysis shows that there are significant differences in timing of diurnal patterns of horizontal and vertical currents and backscatter among the various stations.

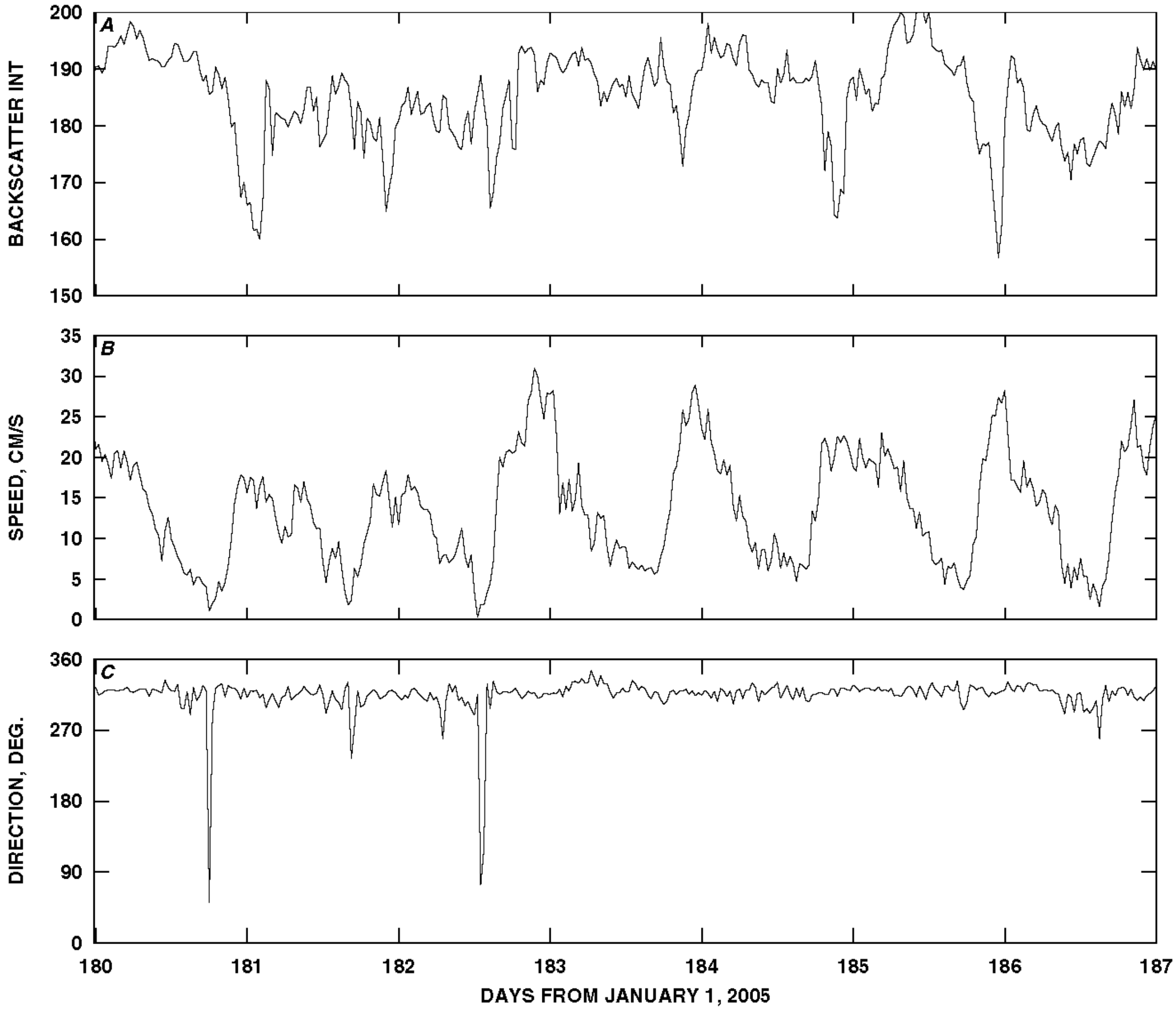

Figure 4. One week of measurements from 6/29/05 (day 180) to 7/6/05 (day 187) by ADCP at station, ADCP1. Measurements are from bin 12 at about 6.7 meters above bottom; water depth was about 14.2 meters.

For detailed analyses of spatial and temporal variations of horizontal and vertical current speeds and backscatter intensity, ADCP measurements from 2005 were processed to compute bar graphs to show diurnal patterns. (As previously described, some additional analyses of ADCP data from 2005 were performed because that data set had the most complete spatial coverage.) The computed bar graphs are included in Appendix B (horizontal velocities), Appendix C (vertical velocities), and Appendix F (backscatter); results are summarized in tables 4 and 5. As part of the analysis, bar graphs from wind measurements were also generated (Appendix H) to show diurnal variations in wind speeds and their relations to diurnal variations in horizontal and vertical water currents and backscatter at the near-surface and near-bottom levels.

In the case of an upward-looking ADCP, the last usable velocity measurement from the ADCP bin that is closest to the air/water interface is determined during post processing by identifying an increase in backscatter (which occurs at a density discontinuity) or alternatively, from the actual water depth. These methods normally work well; however, both techniques are problematic for ADCP data sets from Upper Klamath Lake. First, the large concentration of AFA in the near-surface zone of the lake causes a large increase in backscatter prior to the point where the acoustic signal reaches the boundary. Second, the lake level changes throughout the summer season resulting from a drawdown of just over 1 cm/day. Thus, the last good ADCP bin closest to the water surface at the start of the summer instrument deployment will be invalid within a few weeks. The last good ADCP bin at instrument recovery may be 3-4 bins lower than at start of deployment. Therefore, in order to look at near-surface characteristics, a "near-surface" time series of measurements has been spliced together from appropriate bin data from sequentially lower and lower bins as the deployment progresses and the water depth becomes gradually shallower. The bar graphs in Appendices B, C, and F that display near surface variables for 2005 ADCP data have been generated from those spliced time series data.

Diurnal Patterns in Wind Measurements (2005)

Examination of bar graphs showing diurnal wind patterns (Appendix H and table 4) shows that minimum wind speeds occur during late morning (≈1100-1200) and maximum wind speeds occur during late evening (≈ 2100) at stations MDN, MDL, and HDB-MET. Because Upper Klamath Lake is a wind driven system with little river inflow; horizontal water circulation is expected to correlate with wind patterns. However, times of minimum and maximum horizontal current speeds are spatially variable in the lake because of the effects of bathymetry and geometry on water motion. Details of spatial variations in water motion at the ADCP measurement sites during the 2005 field season are described in the following section.

Table 4. Approximate times of day of maximum and minimum wind speed and maximum and minimum horizontal current speed (both near-surface and near-bottom) in Upper Klamath Lake during the field sample period June 21, 2005 to September 12, 2005. Where appropriate, the meteorological station closest to the corresponding ADCP site is noted.

Station Name	Minimum Wind Speed	Maximum Wind Speed	Minimum Near-Surface Current	Maximum Near-Surface Current	Minimum Near Bottom Current	Maximum Near Bottom Current
ADCP1			16:30	3:00	15:00	22:30
ADCP3 (MDN)	10:15	20:45	21:30	14:30	12:30	03:30
ADCP5			16:30	3:00	16:00	22:00
ADCP6 (MDL)	12:15	21:30	2:30	16:00	10:30	16:00

ADCP7 (HDB-MET)	11:45	19:45	15:00	22:00	10:30	22:00

Spatial Variations in Diurnal Patterns of ADCP Horizontal Velocity Measurements (2005)

The ADCP records from 2005 exhibit diurnal patterns in velocity measurements that appear to correlate with wind or other hydrodynamic or biological processes (tables 4 and 5).

Deployment of ADCP7 was at the south end of the trench on the west side of the lake where water depth was about 5 m. In general, maximum and minimum horizontal current speeds lag the maximum and minimum wind speeds by about two to three hours at the site, except for the minimum water speed near bottom which occurs prior to the minimum wind speed. There is a distinct period of minimum water current speed near surface at about 1500; however, the bar graph of near-bottom speed displays a broad minimum between about 0700 and 1300. Maximum currents near-surface and near-bottom occur at about 2200.

Located in the trench where water depth was about 14 m at the start of the deployment, ADCP1 displays daily patterns of horizontal currents somewhat similar to ADCP7. However, there is a larger phase difference between wind patterns and current patterns (about 5-7 hours near-surface and about 3 hours near-bottom). The daily patterns of maximum and minimum speeds are more pronounced than at ADCP7 and there is a tendency for the bottom currents to lead the near-surface currents. Maximum current speeds occur at about 0300 near-surface and about 2230 near-bottom. Minimum current speeds occur at about 1630 near-surface and about 1500 near-bottom.

ADCP5 was deployed east of Eagle Point in about 5 m of water in an area where the bathymetry contour lines tend to run generally east-west rather than north-south as they do in the trench where ADCP1 was located. At this site, the currents are lower than at ADCP1 or ADCP7 and, as at those sites, tend to oppose the prevailing winds. As a result there is far less distinct daily variation in current speed near surface. The average near-surface current is near 8 cm/s for most of the day although the maximum (about 0300) and minimum (about 1630) occur at times that are close to the times they occur at ADCP1. Near-bottom currents also appear similar to those at ADCP1 with minimum current speeds occurring at about 1600 and maximum current speeds at about 2200 (about a 2-hour delay between winds and currents).

Located further west of Eagle Point than ADCP5, the ADCP deployed at site ADCP3 measured water currents that lack distinct diurnal variations. Current speeds typically range between about 5-6 cm/s although there are some higher values near-surface at about 1430 and near-bottom at about 0330 which do not seem to correlate with local wind speeds. Near-surface minimum current speeds occur near midnight (about 2130-0100 and near-bottom minimums occur near noon.

ADCP6 was the station deployed in the most eastern and shallowest location in the lake during 2005. The highest current speeds near surface occur near 1600 and are completely out of phase with maximum surface currents on the west side of the lake at ADCP7, ADCP5, and ADCP1. Minimum currents occur in early morning near about 0230. Near-bottom currents display an unusual pattern during the day with a short period of slightly lower currents during late morning (about 1030), but little overall variation during the day.

Diurnal Patterns of ADCP Vertical Velocity Measurements (2005)

In interpreting measurements by ADCP, it is critical to remember that the ADCP calculates velocity from the Doppler shift of acoustic backscatter from particles moving in the water (which may not be the same as the water motion). This fact is particularly important when evaluating the calculated vertical velocity. Vertical velocities measured by ADCP may include sediment suspension and settling, plankton migration and settling, and possibly even buoyancy of entrained bubbles near the water surface in addition to actual water motion. Although the measured vertical velocities are substantially larger than typically expected based on numerical model results, the measured vertical velocities for each ensemble (of averaged single pings) is the same order of magnitude as the theoretical standard deviation of the vertical velocity ($\approx$0.3 cm/s). However, the averaging technique used to create the bar graphs and the generally consistent daily patterns of currents and wind suggest that any conclusions inferred from the bar graphs are probably meaningful.

It is therefore potentially possible to quantify the diurnal (vertical) migration patterns of AFA colonies in Upper Klamath Lake. The simplest theoretical model of AFA migration predicts a buoyancy gain (net rising) of colonies during dark hours once excess nutrient stores have been exhausted and the cells are once again energy limited and a buoyancy loss (net sinking) of the blue-green algae during daylight hours after energy saturation is achieved (Porat and others, 2001).

Consideration of the vertical velocities at the five ADCP sites, in conjunction with the backscatter information (discussed below), suggests that the suspended material, which is primarily organic as determined by the analysis of water quality samples that is discussed below, consists of AFA populations that are a mixture of rising and sinking colonies. In many cases, the patterns of vertical velocity observed in the bar graphs (Appendix C and table 5) fit the conceptual model of diurnal migration of AFA, displaying net buoyancy during darkness and net sinking during daylight (Porat and others, 2001). Where there are significant variations from the theoretical diurnal vertical migration pattern of AFA, those differences can be explained by hydrodynamic effects related to water depth variations near the deep channel and wind-driven circulation patterns in the lake, both of which would be expected to affect suspended materials consisting of re-suspended bed sediments and AFA populations. Further detailed analyses of the spatial variations of vertical velocity are beyond the scope of this report.

Table 5. Approximate times of day of maximum and minimum vertical current speed and backscatter intensity (both near-surface and near-bottom) in Upper Klamath Lake during the field sample period June 21, 2005 to September 12, 2005. Where appropriate, the meteorological station closest to the corresponding ADCP site is noted.

Station Name	Minimum Near-Surface Vertical Velocity	Maximum Near-Surface Vertical Velocity	Minimum Near-Bottom Vertical Velocity	Maximum Near-Bottom vertical Velocity	Minimum Near-Surface Backscatter Intensity	Maximum Near-Surface Backscatter Intensity	Minimum Near-Bottom Backscatter Intensity	Maximum Near–Bottom Backscatter Intensity
ADCP 1	7:30	19:00	7:30	17:00	8:30	18:00	21:30	9:30
ADCP 3 (MDN)	14:00	23:00	2:30	20:30	8:00	19:30	12:00	22:30
ADCP 5	3:00	19:30	12:00	22:00	8:00	15:00-17:00	14:30	3:00
ADCP 6 (MDL)	14:00	18:00	8:30	22:30	8:30	17:30	15:00	23:00
ADCP 7 (HDB-MET)	13:30	23:00	11:30	22:30	8:00	18:30	14:30	7:30

Variations in Backscatter Intensity Measurements (2005)

Acoustic backscatter intensity, a surrogate for suspended material, varies seasonally as well as by location in the lake, vertical position in the water column, and time of day. Seasonal variations throughout the 2005 summer field season at the five ADCP sites are shown in figure 5 which displays the filtered values of acoustic backscatter intensity in dB (corrected for transmission losses from acoustic beam spreading and absorption from water). Although the 2005 measurements begin too late in the spring to capture the large increase in backscatter that would likely indicate the start of the blue-green algae bloom, the population decline at the end of July (near day 212) is clearly shown.

As previously described, the backscatter intensity measurements have not been calibrated to convert them to mass concentration. Thus, the results contain instrument differences as well as variations related to differences in suspended material at each site. Therefore the backscatter measurements, as a surrogate for SSC, are not directly comparable among ADCP stations; however, timing of maxima and minima and vertical variations (Appendix F and table 5) determined by individual instruments are meaningful since measurements are corrected for acoustic transmission losses.

Times of maximum near-surface backscatter intensity are similar at the five measurement sites (≈1800) and precede the time of maximum wind speed (≈2100) by about three hours. Similarly, times of minimum near-surface backscatter intensity are nearly simultaneous at the five measurement sites (≈0800) and precede the time of minimum wind speed (about 1100-1200) by about three hours. Times of maximum backscatter near-bottom at the various sites are scattered throughout the day while times of minimum backscatter near-bottom (≈1400) occur about three hours after the minimum wind speeds. The exception is the deep station, ADCP1, where the minimum backscatter near-bottom occurs near 2130. The times of maximum backscatter near-surface at the five ADCP measurement sites also precede the time of maximum upward (or minimum downward) vertical velocity (≈2000-2100) by about two to three hours and precede the time of maximum daily water temperature (about 1900) by one to two hours (Wood and others, 2006). Thus, the maximum backscatter tends to occur in the late afternoon, roughly coincident with the maximum stratification of the water column (Wood and others, 2006). It is beyond the scope of this report to determine if diurnal patterns in near-surface backscatter estimates relate to diurnal variations in vertical migration of AFA, wind patterns, or a combination of multiple factors. Nevertheless, the patterns in backscatter intensity seen in the near-surface and near-bottom bar graphs, especially when viewed with the diurnal variations in vertical velocity and in the context of the daily variations in water temperature are suggestive of diurnal variations from vertical migration of AFA.

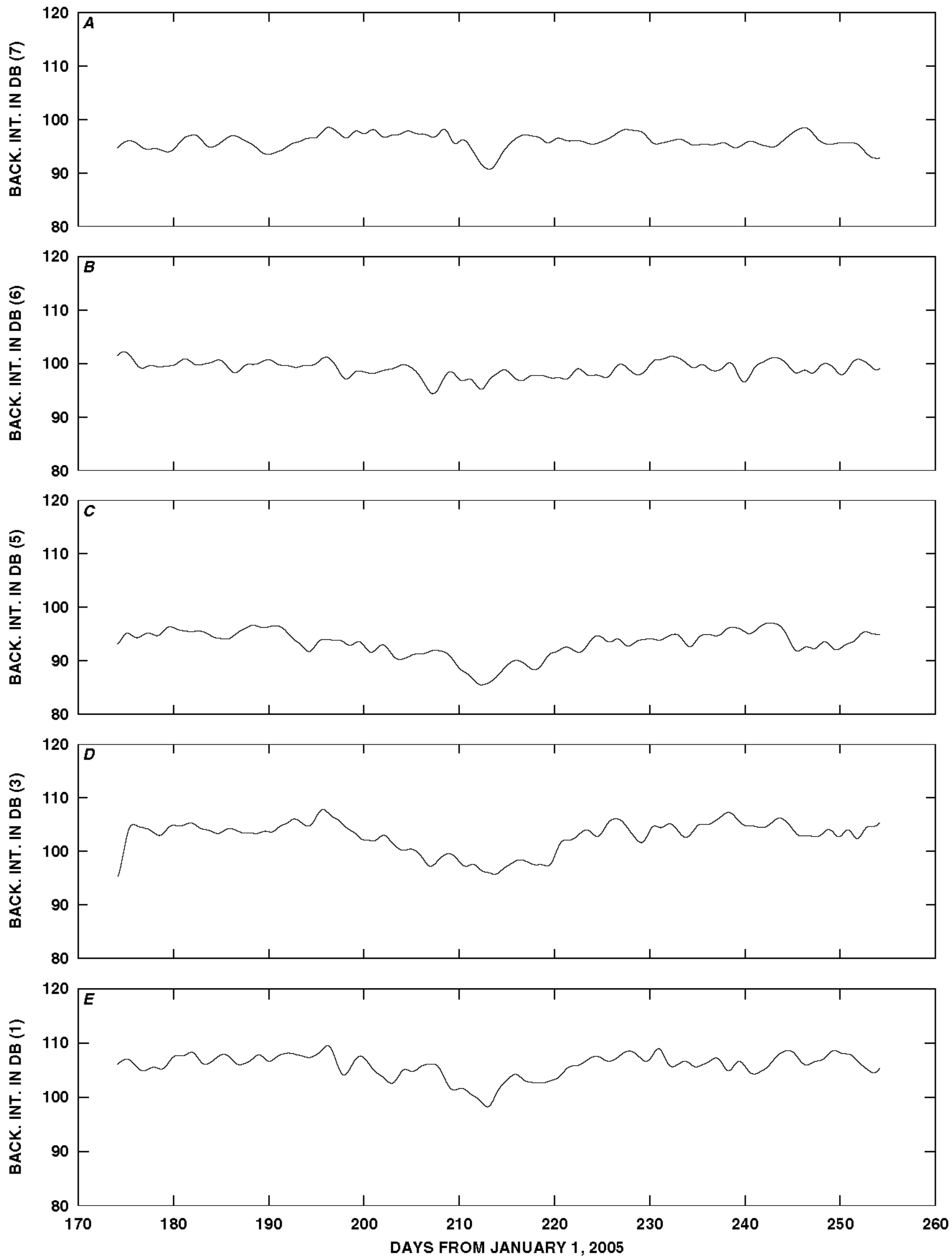

Figure 5. Time series plots of (filtered) ADCP acoustic backscatter intensity from Upper Klamath Lake (near surface) as a surrogate for suspended material. Minimum values near calendar day 212 probably represent the decline of AFA population.

Variations in LISST Data

LISST measurements of characteristics of suspended material (< 250 μm) in Upper Klamath Lake, primarily size distribution, differ from year to year. Those differences may be the result of instrument locations (at ADCP2 and ADCP3 in 2004, near ADCP6 in 2005, and near ADCP9 in 2006) or changes in size distributions and characteristics of SSC from year to year. In 2004, the peak in the size distribution is 166-196 μm and the mean size is about 117 μm. In 2005, the peak in the size distribution is at 86-101 μm, although there is a small peak at 12-14 μm; the mean size is about 105 μm. LISST measurements from 2006 have a mean size of about 63 μm but show a clearly bimodal distribution with peaks at about 6 μm and 86-101 μm. As an example, figure 6, representing the LISST measurement at 1130 on May 25, 2006 (day 145), shows that the size distribution is clearly bimodal but the peak at the smaller size class is a small component of the total measured volume concentration. It should be stressed that the upper size limit for measurements with this model LISST is 250 μm. Particles larger than that (which may include the majority of the AFA colonies) are not seen by the instrument.

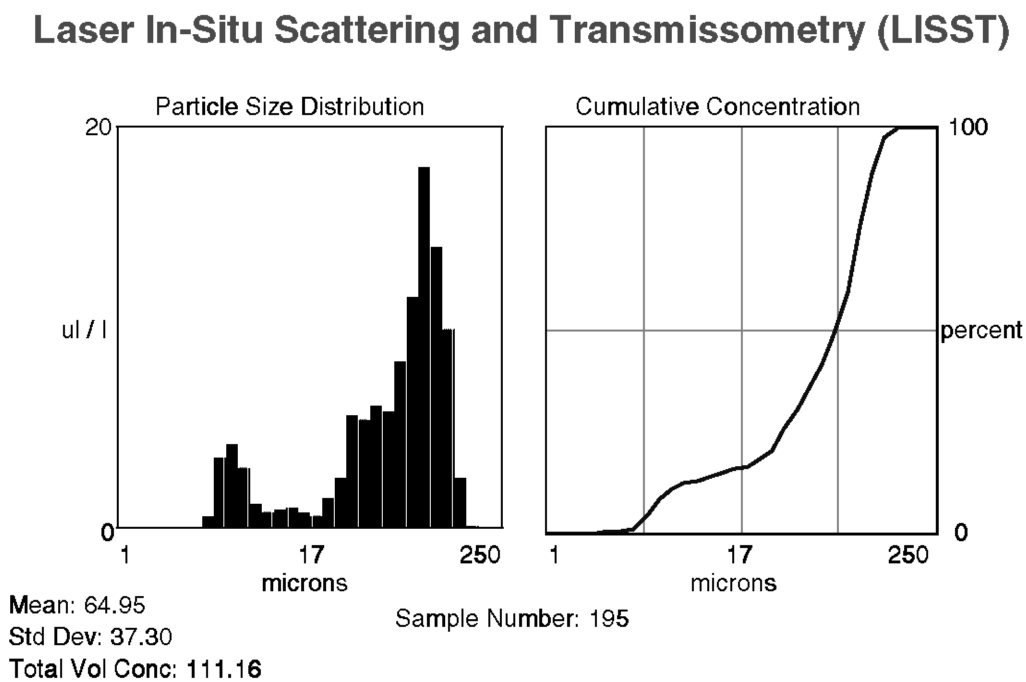

Figure 6. Size distribution and cumulative volume concentration from a LISST measurement made on May 25, 2006 at 1130. Particle size distribution shows a bi-modal character of size distribution. (The graphs are generated from manufacturer supplied software.)

Values of volume concentration in units of μl/l (which may be similar to mass concentration in units of mg/l if particle density is about 1 gm/cm^{-3}) generally ranged between about 25 μl/l to about 100-150 μl/l when the LISST lenses are clean although there are numerous peak values that are substantially higher (Appendix E). Some of those high values may be spurious readings from very large particles in the sample volume blocking the laser or lens. As the percent transmission decreases (from biological fouling) the volume concentration appears to increase proportionately (and probably erroneously); however, there appears to be little effect on particle size until percent transmission falls below 20 percent (either from biological fouling or high concentration that results in multiple scattering). Regardless of the source of decreased transmission, all data are assumed invalid if percent transmission falls below 20 percent.

Analyses of Water Quality Samples (2006)

Sparse water quality measurements available from 2002 indicate that values of vertically integrated SSC in the northern part of the lake were in the range of 90-150 mg/l and values for loss on ignition (LOI), the percent organic to inorganic (on a vertically integrated basis) were about 35 percent organic to about 65 percent inorganic (Wood, T.M., unpub. data, 2002).

Additional discrete water samples were collected and analyzed in 2006. (Two sets of water-quality samples collected in May and July are not included in this analysis because the samples may have been mishandled; results appear unreliable.) The remaining samples, collected on 9/11/06 and 9/25/06 at the two ADCP sites (ADCP1 and ADCP9), contained SSC between about 5 and 43 mg/l at near-bottom, mid-water, and near-surface locations (tables 6a and 6b). The standard deviation of the mass concentration from replicate samples varied from 0-10.5 mg/l. The near-surface values of SSC were slightly higher than the near-bottom values at both the shallow station (by 2.5 and 7.5 mg/l) and the deep station (by 3.0 and 2.5 mg/l); however, the differences, although consistent, are within the range of the standard deviation of the replicate samples.

LOI values for these discrete samples indicate that the percent inorganic ranged between about 5-52 percent (tables 6a and 6b). The inorganic fraction was less in the near-surface samples than in the near-bottom samples at both sites and on both sample dates, consistent with increased AFA population near-surface. The inorganic fraction was about 13 to 21 percent higher in the near-bottom samples at the shallow site, and about 15-16 percent higher in the near-bottom samples at the deep site. Replicate values of the inorganic fraction were generally repeatable within 1- 2 mg/l but the standard deviations of the percent inorganic varied from about 1-10 percent.

Table 6a. Water quality sample results from shallow station (ADCP9) at near-surface, mid-water, and near-bottom locations in water column in 2006.

MONTH	DAY	YEAR	TIME	WATER DEPTH (M)	SAMPLE BELOW SURFACE (M)	SSC (MG/L)	PERCENT INORGANIC (%)
9	11	2006	10:40	3.7	1.0	43	5
9	11	2006	10:40	3.7	1.0	22	14
9	25	2006	15:00	3.6	1.0	14	14
9	25	2006	15:00	3.6	1.0	13	8
9	11	2006	10:50	3.7	1.8	18	22
9	11	2006	10:50	3.7	1.8	15	27
9	25	2006	15:00	3.6	1.7	9	11
9	25	2006	15:00	3.6	1.7	10	30
9	11	2006	11:00	3.7	2.6	37	16
9	11	2006	11:00	3.7	2.6	24	29
9	25	2006	15:00	3.6	2.6	8	38
9	25	2006	15:00	3.6	2.6	4	25

Table 6b. Water quality sample results from deep station (ADCP1) at near-surface, mid-water, and near-bottom locations in water column in 2006.

MONTH	DAY	YEAR	TIME	WATER DEPTH (M)	SAMPLE BELOW SURFACE (M)	SSC (MG/L)	PERCENT INORGANIC (%)
9	11	2006	11:40	12.4	1.5	28	36
9	25	2006	13:40	12.4	2.0	30	17
9	25	2006	13:40	12.4	2.0	33	15
9	25	2006	14:00	12.4	5.5	24	25
9	25	2006	14:00	12.4	5.5	24	21
9	11	2006	12:00	12.4	11.0	25	52
9	25	2006	14:30	12.4	11.0	30	30
9	25	2006	14:30	12.4	11.0	28	32

Summary

Hydrodynamic measurements were made by the USGS in Upper Klamath Lake during four summer seasons (approximately mid-June to mid-September) during 2003 to 2006. Those measurements were primarily water current profiles by ADCP at fixed locations in the lake. Some measurements were made by ADCP from moving boat during 2005 and 2006. Measurements of size distribution of suspended material were made at four locations in the lake. Raw data are presented as time series. Filtered velocity data are provided to remove wind-induced variations from water currents. Bar graphs of horizontal and vertical current speed, acoustic backscatter, and wind speed are provided to discern diurnal variations as they might relate to wind patterns over the lake and vertical migration of AFA populations. Field data may be accessed online at *http://pubs/usgs.gov/of/2007/1279/data*.

References Cited

Agrawal, Y. C., Pottsmith, H. C., 1993, Optimizing the kernel for laser diffraction particle sizing, Applied Optics, 32, p. 4285-4286.

Agrawal, Y. C., Pottsmith, H. C., 1994, Laser diffraction particle sizing in STRESS, Con. Shelf Res., 14, p. 1101-1121.

Agrawal, Y. C., McCave, I. N., Riley, J. B., 1991, Laser diffraction size analysis, In: Principles, Methods, and Application of Particle Size Analysis, J. M Syvitski, (Editor), Cambridge Univ. Press, Cambridge, p. 119-128.

Agrawal, Y. C., Pottsmith, H. C., Lynch, J., Irish, J., 1996, Laser instruments for particle size and settling velocity measurements in the coastal zone, Oceans '96, Institute of Electrical and Electronic Engineers, p.1135-1142.

Burau, J. R., Simpson, M. R., and Cheng, R. T., 1993, Tidal and residual currents measured by an acoustic Doppler current profiler measured at the west end of Carquinez Strait, San Francisco Bay, California, March to November, 1988: U. S. Geological Survey Water Resources Investigations Report 92-4064, 76 p.

Cheng, R. T., Gartner, J. W., and Wood, T. M., 2005, Modeling and model validation of wind-driven circulation in Upper Klamath Lake: Proceedings of the 2005 World Water and Environmental resources Congress, May 15-19, 2005, Anchorage, Alaska, Environmental and Water Resources Institute of the American Society of Civil Engineers.

Gartner, J. W., 2004, Estimating suspended solids concentrations from backscatter intensity measured by acoustic Doppler current profiler in San Francisco Bay, California, Mar. Geol. 211 (2004), p. 169-187.

Gartner, J. W., Cheng, R. T., Wang, P. F., and Richter, Kenneth, 2001, Laboratory and field evaluations of LISST-100 instrument for suspended particle size determinations, Mar. Geol. 175 (2001), p. 199-219.

Gartner, J. W. and Ganju, N. K., 2002, A preliminary evaluation of near-transducer velocities collected with low-blank acoustic Doppler current profiler, Proceedings, ASCE 2002 Hydraulic Measurements and Experimental Methods Conference, Estes Park, CO, 7/28/02-8/1/02.

Hildebrand, Hillary, Row, Gordon, 1995, Laser light scattering in particle size analysis, American Ceramic Soc. Bulletin, 74, p. 49-52.

McCave, I. N., Bryant, R. J., Cook, H. F., Coughanowr, C. A., 1986, Evaluation of a laser-diffraction-size analyzer for use with natural sediments, J. Sed. Petrol., 56, p. 561-564.

Porat, Ram, Teltsch, Benjamin, Perelman, Alex, and Dubinsky, ZVY, 2001, Diel buoyancy changes by the cyanobacterium Aphanizomenon ovalisporum from a shallow reservoir, Journal of Plankton Research, Vol 23, No. 7, p. 753-763.

Pottsmith, H.C., Bhogal, V.K., 1995, In situ particle size distribution in the aquatic environment. Presented at The 14th World Dredging Congress, Nov. 1995, Amsterdam, The Netherlands, 13 p.

R.D. Instruments, Inc., 1996, Acoustic Doppler current profilers: Principles of operation: A practical primer: San Diego, Calif., RD Instruments, Inc., 36 p.

RD Instruments, 1997, DR/SC Acoustic Doppler current profiler: Technical manual. RD Instruments, San Diego, CA, 380 p.

Reichel, G., Nachtnebel, H.P., 1994, Suspended sediment monitoring in a fluvial environment: advantages and limitations applying an acoustic Doppler current profiler. Water Research 28 (4), p. 751–761.

Simpson, M. R., 2001, Discharge measurements using a broad-band acoustic Doppler current profiler, U.S. Geological Survey Open-File Report 01-1, 123 p.

Thevenot, M.M., Prickett, T.L., Kraus, N.C., 1992, Tylers Beach, Virginia, dredged material plume monitoring project 27 September to 4 October 1991. Dredging Research Program Technical Report DRP-92-7, US Army Corps of Engineers, Washington, DC, 204 p.

Traykovski, Peter, Latter, R. J., Irish, J. D., 1999, A laboratory evaluation of the laser in situ scattering and transmissometry instrument using natural sediments, Mar. Geol., 159, p. 355-367.

Walters, R.A. and Heston, Cynthia, 1982, Removing tidal-period variations from time-series data using low-pass digital filters: Journal of Physical Oceanography, v. 12, p. 112-115.

Whitton, B. A. and Potts, M., eds., 2000, The Ecology of Cyanobacteria, Kluwer Academic Publishers, Dordrecht, 669 p.

Wood, T. M., 2001, Sediment oxygen demand in Upper Klamath and Agency Lakes, Oregon, 1999: U. S. Geological Survey Water Resources Investigations Report 01-4080, 13 p.

Wood, T.M., and Cheng, R. T., 2006, Use of UnTRIM to investigate dissolved oxygen transport in Upper Klamath Lake, Oregon: Proceedings of the Seventh International Conference on Hydroscience and Engineering, Philadelphia, PA, September 2006. http://hdl.handle.net/1860/732.

Wood, T. M., Hoilman, G. R., and Lindenberg, M. K., 2006, Water-quality conditions in Upper Klamath Lake, Oregon, 2002-04: U. S. Geological Survey Scientific Incvestigations Report 2006-5209, 52 p.