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Experiences using Acoustic Doppler Current Profilers (ADCP) for Physical Model Calibrations

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ABSTRACT: The US Bureau of Reclamation's Water Resources Research Laboratory has been using acoustic Doppler current profilers (ADCPs) since 1994 to collect near- and far- field velocity profiles to describe velocity fields in and around hydraulic structures. This velocity data is very useful in designing and validating hydraulic models, as well as describing performance of existing hydraulic structures. The application to be addressed in this paper involves measuring near-field velocities in a lake near a proposed positive barrier fish screen. This paper will describe an application using moving-boat ADCP systems.

1. Background

A-Canal withdraws water from Upper Klamath Lake just upstream from the Link River Dam to serve the Klamath Project in south-central Oregon and northern California (see figs. 1 and 2). The reservoir is a natural lake whose level was raised several feet by the 1921 construction of Link River Dam. The canal entrains juvenile and adult fish of two endangered species of lake suckers—the Lost River sucker and the shortnose sucker. A Biological Opinion originally issued in 1992 by the U. S. Fish

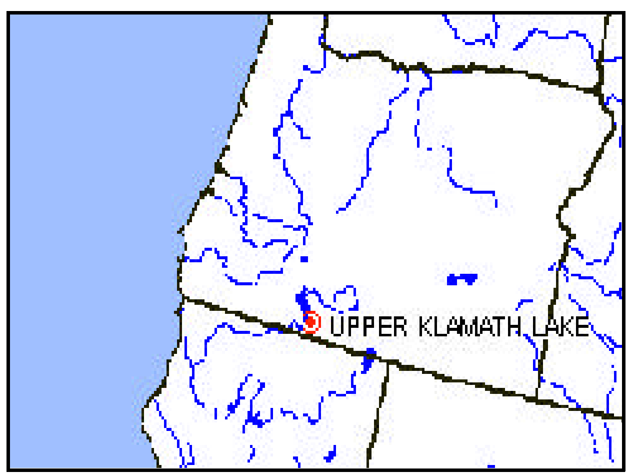

Figure 1. — Location map showing Upper Klamath Lake on the Klamath River just north of the California-Oregon border.

& Wildlife Service identified Reasonable and Prudent Alternatives (RPA) requiring Reclamation to reduce entrainment of individuals of both species.

One alternative proposed for reducing sucker entrainment into A-Canal is construction of a positive barrier fish screen facility at the headworks of A-Canal. To support engineering evaluation of this alternative, staff from Reclamation's Water Resources Research Laboratory (WRRL) collected velocity data on Upper Klamath Lake in the vicinity of the headworks using an ADCP under three different operating conditions during 1998. These data will provide designers with information that will be useful for identifying potential locations and layouts for a screen structure. The data will also be used by the WRRL for calibration and operation of a physical hydraulic model of the proposed screen structure in their Denver laboratory. This model study will be carried out as part of the design process.

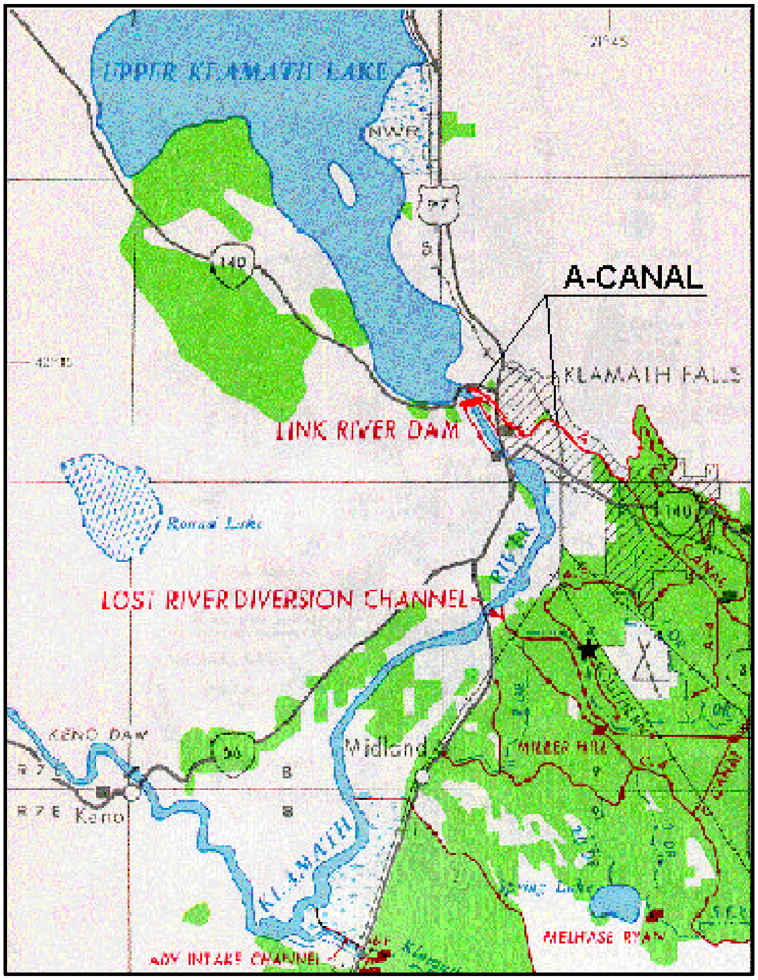

Figure 2. — A-Canal diverts water from the southern tip of Upper Klamath Lake just upstream of Link River Dam. Diversions are also made at Link River Dam into two power canals, one on each abutment.

2. Data Collection

Data were collected using an RD Instruments broadband ADCP, operated from a moving boat. The ADCP uses the Doppler shift principle to measure velocities along four acoustic beams projected downward below the moving boat. The instrument sends out precise acoustic pulses (called pings) and then listens for backscattered acoustic signals reflected off of acoustic scatterers in the water column (e.g., suspended sediment). The Doppler shift of the backscattered signal is proportional to the velocity of the scattering particle. The beams diverge both longitudinally and laterally as shown in figure 3, so that the velocity reported by the instrument is the average of measurements made along each of four different acoustic beams, rather than a measurement at a single point beneath the instrument. Individual velocity measurements are made within discrete vertical depth cells, or bins, with a height of 25 centimeters each, yielding a velocity profile from near the surface to near the bed. Velocities cannot be measured very near the surface because the transducer must be submerged and because there is some time delay between the send and receive modes of operation for the instrument. Velocities also cannot be measured very near the bed (approximately the last 10 percent of the depth) due to a phenomenon called side-lobe interference. Three orthogonal components of velocity are measured; an internal compass allows the velocities to be referenced to the Earth coordinate system (east/north/up). Tilt sensors are used to correct for any pitch/roll errors in depth measurements. In addition to the velocity data, the ADCP records the bathymetry along the transect. Dedicated bottom tracking pings are collected to track the motion of the ADCP relative to the channel bottom using the same Doppler shift technique used to measure velocity. This measurement allows the water velocity measurements to be corrected for the relative boat motion, and permits tracking of the position of the instrument during the transect. A more detailed description of ADCP operation can be found in RD Instruments' primer on ADCP technology (RD Instruments 1989).

A laptop computer was used to configure the ADCP and collect the data. A portable global positioning system (GPS) was also connected to the laptop computer so that continuous GPS data were recorded simultaneously with the velocity data. The GPS was also used to record waypoints at the beginning and end of each transect. Total time required to record about 15 to 20 transects was typically 2 to 4 hours. We did not make any attempt to use the same transect lines on the three different dates, but rather just tried to cover the area of interest in approximately the same level of detail for each visit.

The ADCP used for this work was a 1200 kHz system which is best suited for this shallow water application. Reclamation also uses ADCP's with 300 kHz and 600 kHz transducer heads for deeper water applications, such as large rivers or deep reservoirs.

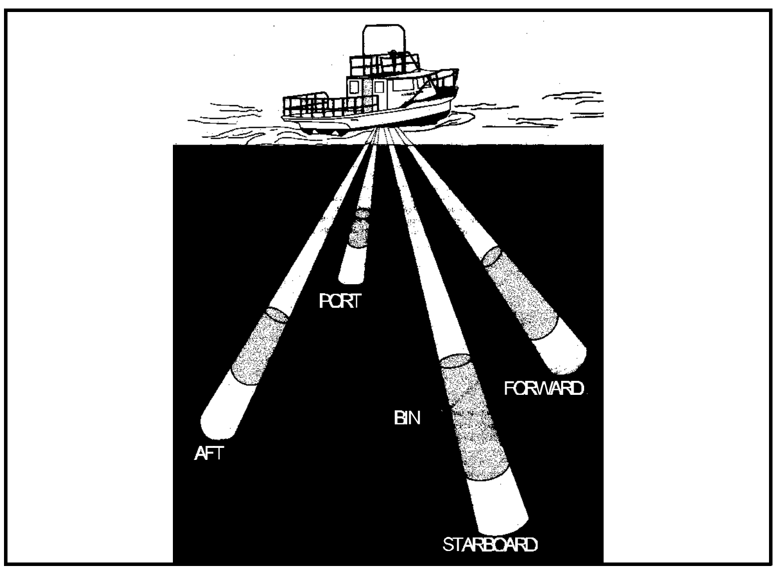

Figure 3. — Typical acoustic beam configuration for a boat-mounted ADCP.

Velocity data were collected on three dates, under three different operating conditions, as summarized in table 1. In addition to differences in lake level and A-Canal flowrate, the flow through the spillways, outlets, and power canals at Link River Dam is significant because it must pass by the A-Canal headworks, thus influencing the velocity field in the vicinity of the intake.

Table 1. — Hydraulic conditions during ADCP data collection visits.

Date	Upper Klamath Lake Elevation, ft	A-Canal Diversion Flow, ft^3/s*	Flow Past Link River Dam, ft^3/s	Number of Transects
May 12, 1998	4143.08	355	4020	16
July 14, 1998	4142.66	1005	1460	22
Sept. 16, 1998	4140.20	1000	1373	14

* To convert from ft^3/sec to m^3/sec multiply by 0.0283.

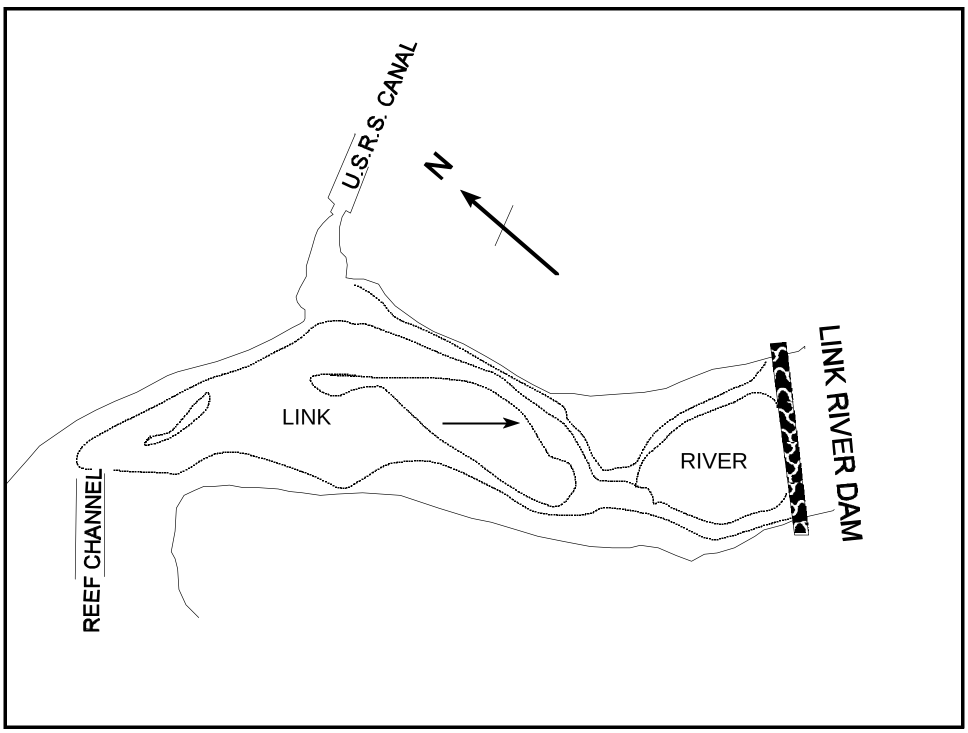

Figure 4. Plan view of the Link River arm of Upper Klamath Lake showing the A-Canal headworks (at top, labeled U.S.R.S. Canal), Link River Dam, and the excavated reef channel (bottom left) The main body of Upper Klamath Lake is below and to the left of the area shown in this view. Link River Dam is at the right side of the figure.

The first two data collection efforts coincided with near-maximum reservoir water levels and relatively low and high ratios of withdrawal to bypass flow, respectively. In September the reservoir was drawn down and diversions into A-Canal were near the maximum values typically experienced during the late summer and early fall months. This was a very wet year in the Klamath Falls area, and the lake level stayed much higher than normal until late in the summer. The flow conditions on September 16 were set specifically for our data collection, with the A-Canal headworks being opened about 30 minutes prior to the beginning of data collection.

Figure 4 shows a general plan view of the area in which measurements were made. Features to note include the reef channel at the entrance of the Link River arm of the lake, the orientation of the A-Canal intake channel and headworks (labeled U.S.R.S. Canal), and the location of Link River Dam.

Figures 5, 6, and 7 show the ADCP transects along which data were collected on each of the three dates. The transect locations were computed using the starting GPS waypoint for each transect and the subsequent relative movement computed by the bottom-tracking feature of the ADCP. The area covered by the transects was 8+ acres (3.2 hectares). The approximate channel boundaries and the location of the A-Canal headworks and the Lakeshore Drive bridge are shown on the figures.

In addition to the raw velocity data, the ADCP computes the discharge across each transect line. This can be used as an indicator of data quality. Table 2 summarizes the discharges measured by the ADCP and compares them with the flows reported by the project operators for each day. The ADCP-measured flows are well within the expected accuracy range of the instrument which is usually ±5 percent of the actual discharge.

3. Velocity Data Analysis

Figures 5, 6, and 7 show the plan-view velocity fields approaching the A-Canal headworks for the May, July, and September data sets, respectively. These figures were constructed using the depth-averaged velocities at each point on each transect; each vector is the average of the east and north velocities measured throughout the depth of the water column. Several interesting features of the flow field can be observed in this presentation of the data.

Each figure shows flow entering the A-Canal intake channel primarily from the south and southwest. The flow vectors point almost straight north along the east bank of the Link River arm of the lake, just south of the A-Canal intake. This effect is most pronounced in the September 16 data, when the canal withdrawal was near maximum and the lake level was low (El. 4140.20 ft).

The factors that produce these flow conditions can be understood by focusing first on the upstream end of the reach in which measurements were made. In the May and July data (figs. 5 and 6) the location of the reef channel which was excavated through

Table 2. — Comparison of ADCP Measurements of Discharge

Date	Transect Description	Average ADCP Discharge (ft^3/s)* and Number of Transects	Discharge Reported by Project, ft^3/s	Percent Difference
May 12	Across Link River Arm, Upstream from Headworks	4603 (9 transects)	4375	+5.2
	Across A-Canal Headworks	408 (2 transects)	355	+14.9
	Across Link River Dam, Downstream from Headworks	4257 (5 transects)	4020	+5.9
July 14	Across Link River Arm, Upstream from Headworks	2575 (12 transects)	2465	+4.4
	Across A-Canal Headworks	995 (3 transects)	1005	-1.1
	Across Link River Dam, Downstream from Headworks	1350 (7 transects)	1460	-7.5
Sept. 16	Across Link River Arm, Upstream from Headworks	2388 (6 transects)	2373	+0.6
	Across A-Canal Headworks	997 (4 transects)	1000	-0.3
	Across Link River Dam, Downstream from Headworks	1368 (4 transects)	1373	-0.4

* To convert from ft^3/sec to m^3/sec multiply by 0.0283.

the reef at the entrance to the Link River arm is evident by the high velocities in portions of transects collected upstream of Lakeshore Drive. Data were not collected in this area during September because shallow areas made access difficult. This acceleration of flow through the reef channel and the general right hand bend as flow enters the Link River arm of the lake produces a flow concentration along the left bank (looking downstream) as the flow approaches the Lakeshore Drive bridge. As flow passes through the bridge section, it continues in a southeasterly direction, rather than turning directly east to enter the A-Canal intake. This is caused by the momentum the flow has attained in passing through the bridge section, and the relatively shallow depths on the east side of the channel downstream from the bridge, which restrict the flow through this area. The effect is that the flow goes past the A-Canal intake, and finally turns back to the north and proceeds up the east side of the channel into the A-Canal intake. This has been described in the past by those familiar with the site as a large eddy causing flow to enter the A-Canal intake from what is often described as the downstream direction. Although the end result is similar, the relative influence of momentum and channel bathymetry in producing this effect probably varies with different operating conditions. When flows over Link River Dam are high (e.g. in May), momentum has a greater influence. When the lake level is reduced (e.g. in September), the influence of bathymetry is increased.

The eddy line is quite apparent in figure 5 (May 12 data). The transect collected in front of the canal intake nearly follows the eddy line, as shown by near zero velocities along most of the transect. All three data sets show a region of poorly organized flow along a line beginning just south of the east abutment of the Lakeshore Drive bridge, and extending to the southeast.

These flow patterns have implications for the design of a fish screen at this site. For a fixed-plate screen to take advantage of sweeping flows toward Link River Dam, the screen would have to be located well out into the body of the Link River arm of the lake, beyond the eddy line apparent in figures 5 through 7. This would produce a very large and expensive structure. If a fixed-plate screen were located closer to the headworks, inside of the eddy line, then approach flows would actually be generally northward, flowing away from Link River Dam. It may be difficult in this case to meet sweeping velocity criteria. A V-oriented screen installed farther downstream in the throat of the intake channel might overcome this problem, but would require a more elaborate bypass system to return fish to the lake.

A sample of a typical ADCP transect has been included in figure 8. This figure shows the bottom profile and the vertical variation of the north velocity component as a function of distance along the transect line. The figure was constructed so that the zero of the horizontal axis is the beginning of the transect and the viewer is looking toward the A-Canal intake This figure illustrates the relatively shallow flow depth in the region south of the east bridge abutment, and the dramatic variation in flow direction and magnitude along the course of some of the transects. The flow is northward toward A-Canal in a narrow region along the east bank, and southward toward Link River Dam on the west side of the channel.

4. Conclusions

The ADCP data collected between May and September 1998 do an excellent job of describing the flow conditions in the vicinity of the A-Canal intake. In general, flow approached the intake channel from the south, along the east bank of the Link River arm of Upper Klamath Lake. This effect was observed under all operating conditions observed in 1998. This observation has implications for the design of a fish screen structure at this site. The data presented here should be useful in the development of conceptual designs, and will also be used to establish appropriate boundary conditions in a future physical hydraulic model study of the proposed fish screen structure.

In general, the moving-boat ADCP and GPS system has proven to be a valuable tool for collecting data both before and after the design and hydraulic modeling of large hydraulic structures.

5. References

RD Instruments, "Acoustic Doppler Current Profilers Principles of Operations: A Practical Primer," San Diego, CA, 1989.

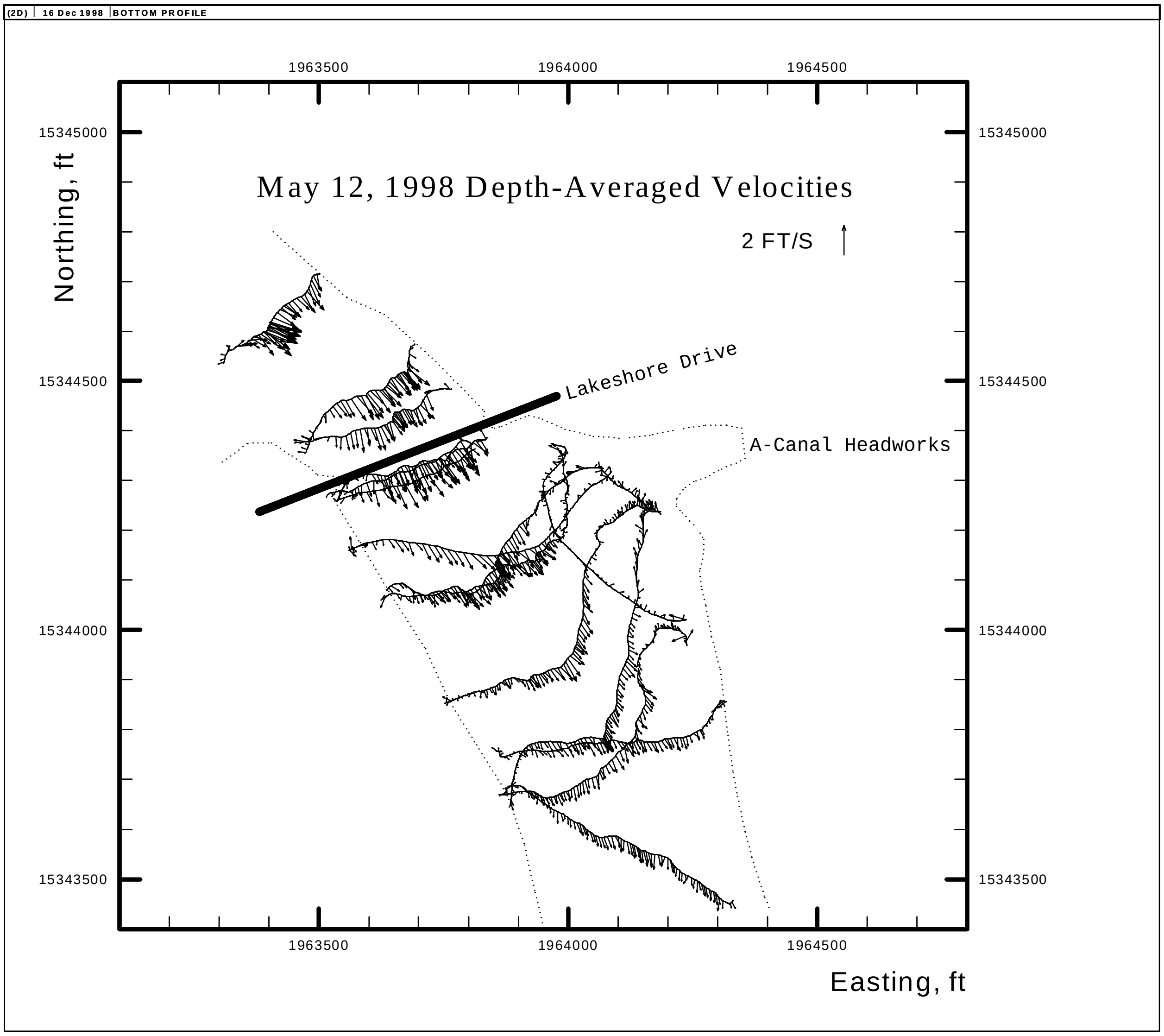

Figure 5. Depth-averaged velocity vectors for ADCP transects collected May 12, 1998. Flow into A-Canal was 355 ft^3/s, and flow toward Link River Dam was 4020 ft^3/s. Upper Klamath Lake elevation was 4143.08. For clarity, vectors are shown for only each fourth data point along each transect.

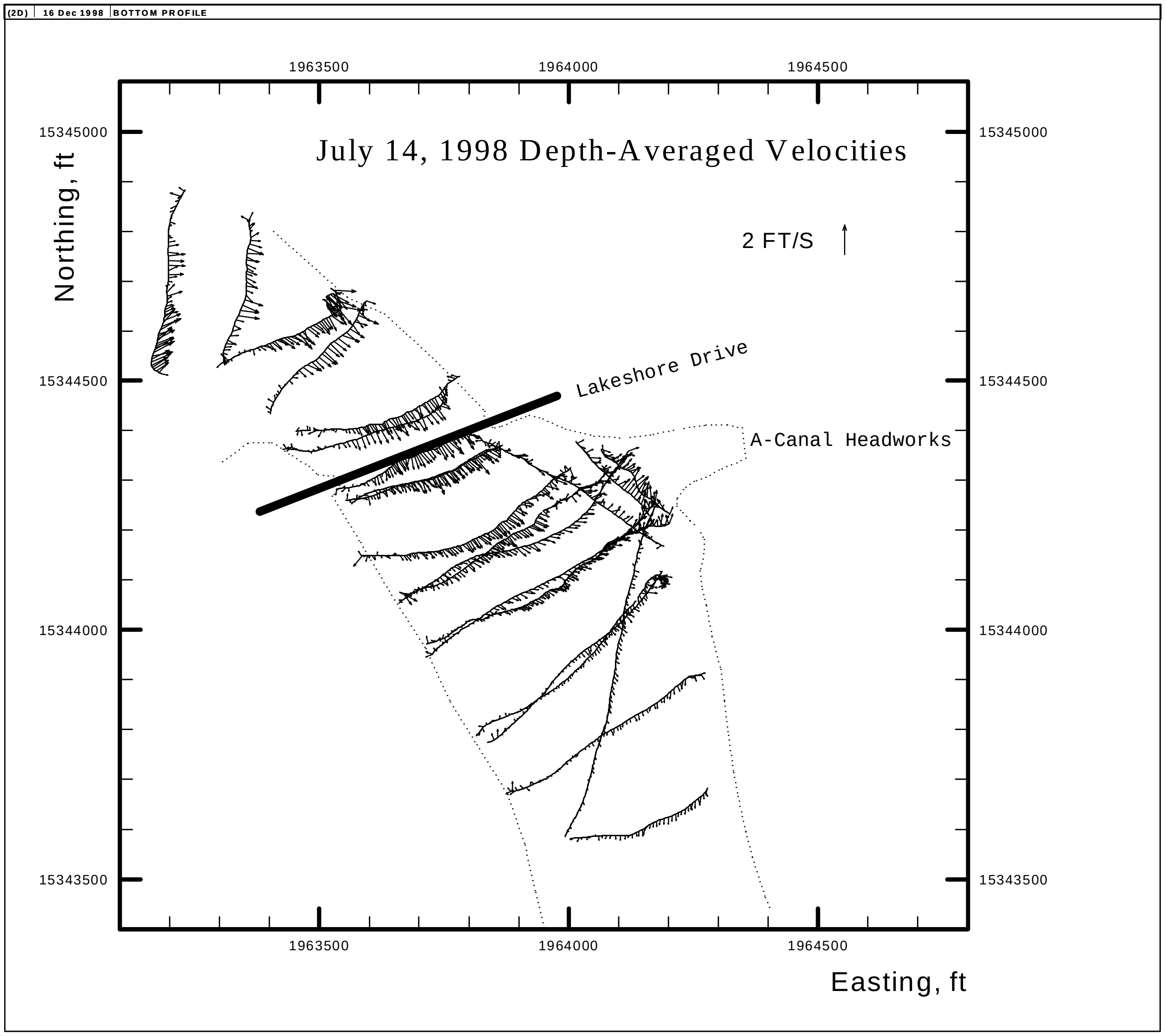

Figure 6. — Depth-averaged velocity vectors for ADCP transects collected July 14, 1998. Flow into A-Canal was1005 ft^3/s, and flow toward Link River Dam was1460 ft^3/s. Upper Klamath Lake elevation was 4142.66. For clarity, vectors are shown for only every other data point along each transect.

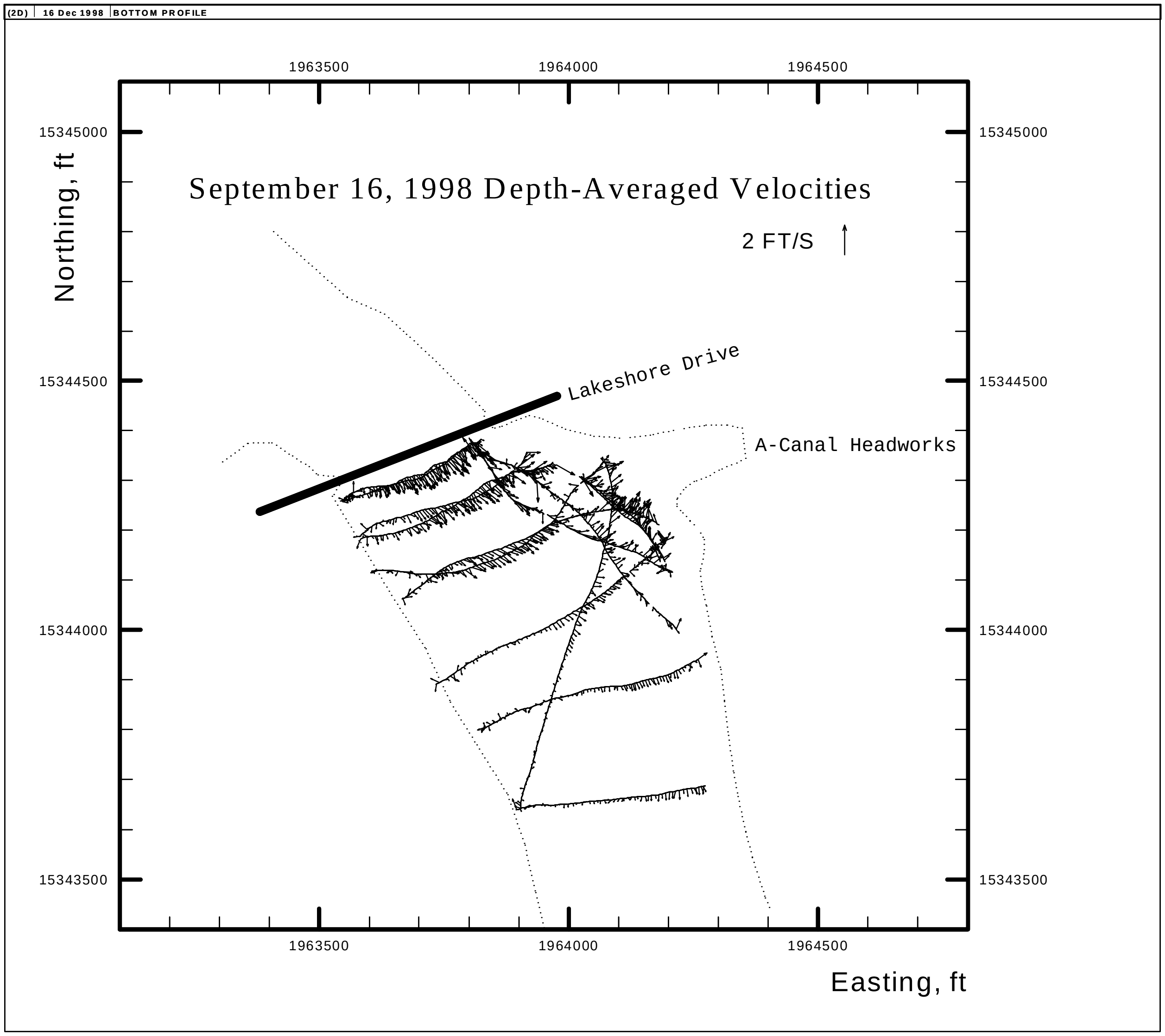

Figure 7. — Depth-averaged velocity vectors for ADCP transects collected September 16, 1998. Flow into A-Canal was 1000 ft^3/s, and flow toward Link River Dam was 1373 ft^3/s. Upper Klamath Lake elevation was 4140.20. For clarity, vectors are shown for only every other data point along each transect.

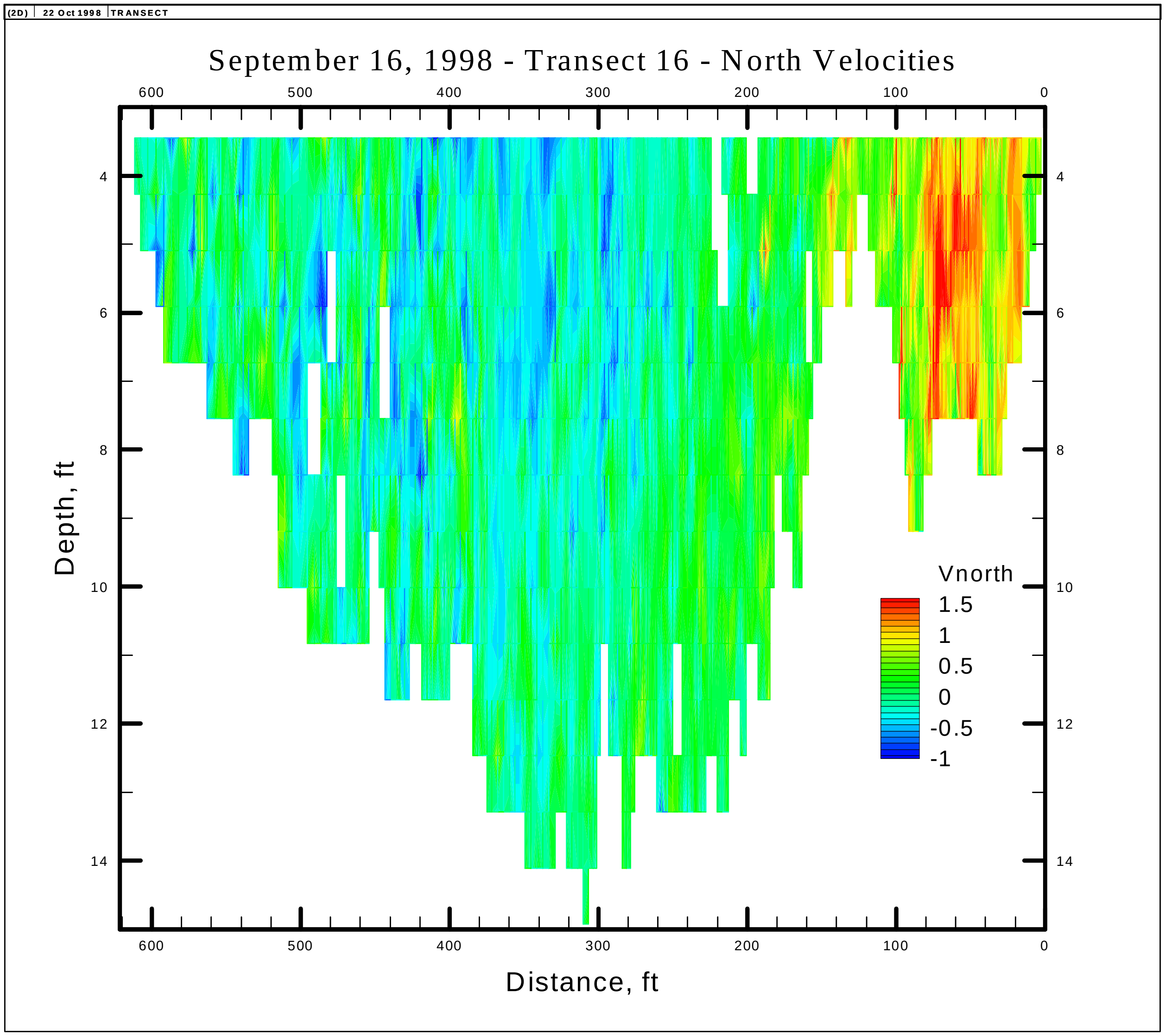

Figure 8. — ADCP velocity data collected on transect 16 across the Link River arm of Upper Klamath Lake, September 16, 1998. Colors indicate the magnitude of the north velocity vector. View is toward the A-Canal headworks from Link River Dam. The left edge of the plot is on the west bank of the Link River arm of the lake, while the right edge of the plot is at the east bank, just south of the A-Canal intake channel. The negative north (south) velocities at the left edge of the plot indicate flow toward Link River Dam, while the positive velocities on the right side of the plot are northward into the A-Canal intake.