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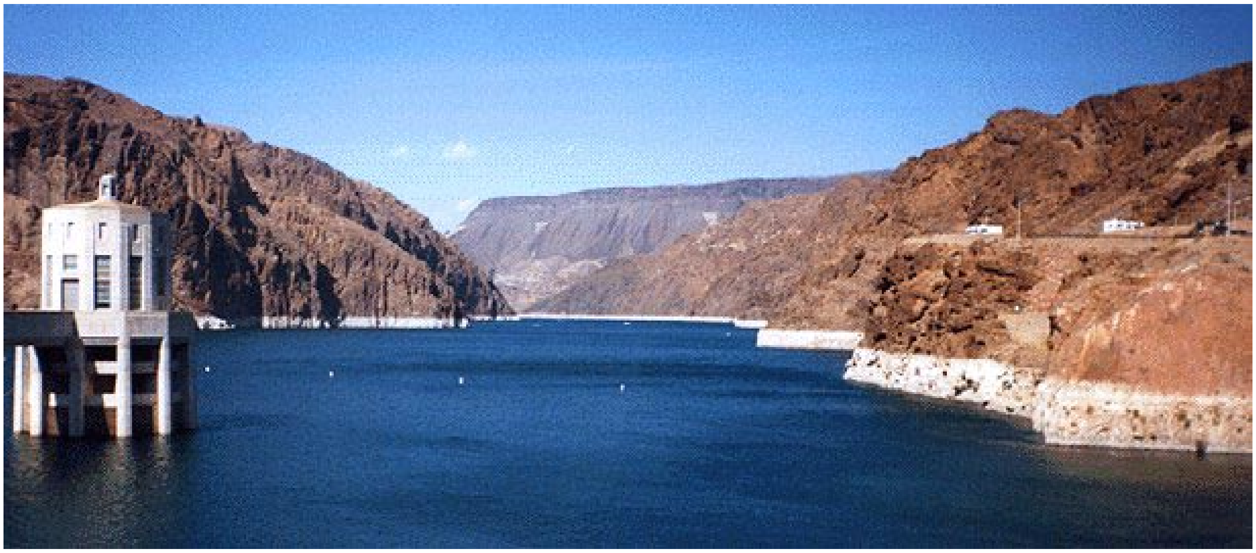
Hydraulic Laboratory Report HL-2009-08

Acoustic Doppler Current Profiler Measurements Near the Proposed Southern Nevada Water System Intake No. 3, Lake Mead, Nevada



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14. ABSTRACT

In response to recent drought conditions and a large drop in Lake Mead's water surface elevation, the Southern Nevada Water Authority is adding a deep water intake in Lake Mead to supply raw water to the Southern Nevada Water System. This project involved collecting acoustic Doppler current profiler data near the new intake (Intake No. 3) site in Lake Mead's Boulder Basin. A comprehensive understanding of seasonal reservoir currents in the vicinity of the new intake will allow SNWS operators to effectively operate their three intakes supplying raw water to their water treatment facilities. ADCP and water quality profiles were collected on a bi-monthly schedule for a period of two years in an effort to document the seasonal reservoir current characteristics in the vicinity of the proposed intake. A summary of seasonal reservoir currents and water quality characteristics at the new intake site and other locations in Lake Mead are presented. For the period studied, current and water quality profile data indicate the new water intake is located at a favorable site and the new intake should meet the water quality objectives. In addition, selective withdrawal modeling was performed to predict raw water quality and the withdrawal zone characteristics.

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Lake Mead, acoustic Doppler current profiler, water quality profiles, water intake, reservoir stratification, interflow, modeling, density currents, selective withdrawal modeling

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Hydraulic Laboratory Reports

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Cover Photo: Photograph of Hoover Dam's forebay, looking toward Black Canyon.

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Purpose and Need

The Southern Nevada Water Authority (SNWA) has begun construction on a deep-water intake in Lake Mead serving the Southern Nevada Water System (SNWS). This intake project description was adapted from the Finding of No Significant Impact Document[1]. For most of the last five decades, Lake Mead has generally operated within a 40-foot elevation range, between approximately 1,180 and 1,220 ft above mean sea level (AMSL). As of August 2006, the water surface elevation of Lake Mead was 1,127 ft AMSL which was 50 ft below the normal low-pool elevation. In July 2006, the Bureau of Reclamation's two-year projected reservoir operation levels for Lake Mead indicated that the lake would drop to elevation 1,127 ft AMSL by the end of 2006, and would continue drop to elevation 1,105 ft AMSL by the middle of 2008.

The existing SNWA water system intakes (No. 1 and No. 2) withdraw water (up to 600 MGD each) from a zone extending vertically 20 to 30 ft above the intake openings. As the reservoir surface elevation drops, the existing intake pumping facilities require more energy to lift water this greater distance, with a corresponding decrease in capacity. The gradual decrease in system pumping capacity with lowering lake levels is serious, but can be mitigated by adding more pumps. However, if the lake level drops far enough, the intake systems will become completely inoperable. Elevation 1,050 ft is the approximate lake surface level at which Intake No. 1 would become inoperable. Elevation 1,000 ft is the approximate lake level at which Intake No. 2 would cease to be operable. Construction of the new Intake No. 3 will ensure that SNWA could maintain full system capacity (1,200 million gallons per day) at lake levels below El. 1,000 ft. Although the pumping station for the proposed intake is intended to be capable of operation only down to lake elevations of 1,000 ft AMSL, the selection of the location and depth of the intake opening are also considered opportunities for enhancing access to better water quality. In Lake Mead, the best water quality is generally found below the metalimnion that separates the epilimnion from the hypolimnion. A target intake opening at elevation 860 ft was established so that water would be drawn from well below the metalimnion (thermocline), even at low lake levels. This new intake will benefit the community water supply by providing more reliable access to better water quality and minimizing the need for application of additional treatment processes, as long as lake levels remain at 1,000 ft AMSL or higher.

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[1] Finding of No Significant Impact, Lake Mead Intake No. 3 Project, Lake Mead National Recreation Area, Clark County, Nevada

Introduction

The Southern Nevada Water Authority requested the Bureau of Reclamation's Hydraulic Investigations and Laboratory Services Group to collect acoustic Doppler current profiler (ADCP) data near the Southern Nevada Water System's (SNWS) new intake (Intake No. 3) in Lake Mead's Boulder Basin. A comprehensive understanding of seasonal reservoir currents in the vicinity of the new intake will allow SNWS operators to effectively operate their three intakes to supply high quality raw water to their water treatment facilities.

For this project, velocity and water quality profiles were collected on a bi-monthly schedule for a period of two years in an effort to document the seasonal reservoir current characteristics in the vicinity of the proposed SNWS Intake No. 3 in Lake Mead (Site ID: CR348.4NW0.8). Reclamation was responsible for collecting ADCP data, and SNWS was responsible for collecting water quality (WQ) profiles. A selective withdrawal model was used to estimate the water quality for Intake No. 3 withdrawals and to determine the seasonal variation in the upper limit of the intake's withdrawal zone.

When time permitted, additional sampling sites were visited to collect ADCP and WQ profile data to document reservoir currents and WQ characteristics at other key locations in Boulder Basin. The scope of work for this project did not include detailed analysis of these supplementary data sets; however, these data sets were used to describe hypolimnetic current patterns in Boulder Basin and the data are available for detailed analysis.

Figure 1 is a map of the sites visited over the period of study. The Hoover Dam sampling site (CR342.2) was visited most frequently in an effort to document hypolimnetic currents generated by Hoover Dam releases. The penstock intake towers at Hoover Dam have gates at elevations 1045 ft and 895 ft. Water entering the gates at El. 895 is a primary source of hypolimnetic currents in Boulder Basin.

This report summarizes the reservoir current and water quality data that were collected from June 2007 through August 2009.

Table 1. Geographic coordinates of sampling sites visited during this project

Location	Latitude (°)	Longitude (°)
SNWS Intake No. 3 @ CR348.4NW0.8	n/a	n/a
LV-A Buoy @ LVB 8.3	N 36.08320	W 114.77296
SNWS Intakes No. 1 and 2	n/a	n/a
Sentinel Island @ CR346.4	N 36.05930	W 114.73855
Hoover Dam @ CR342.25	N 36.01557	W 114.73476

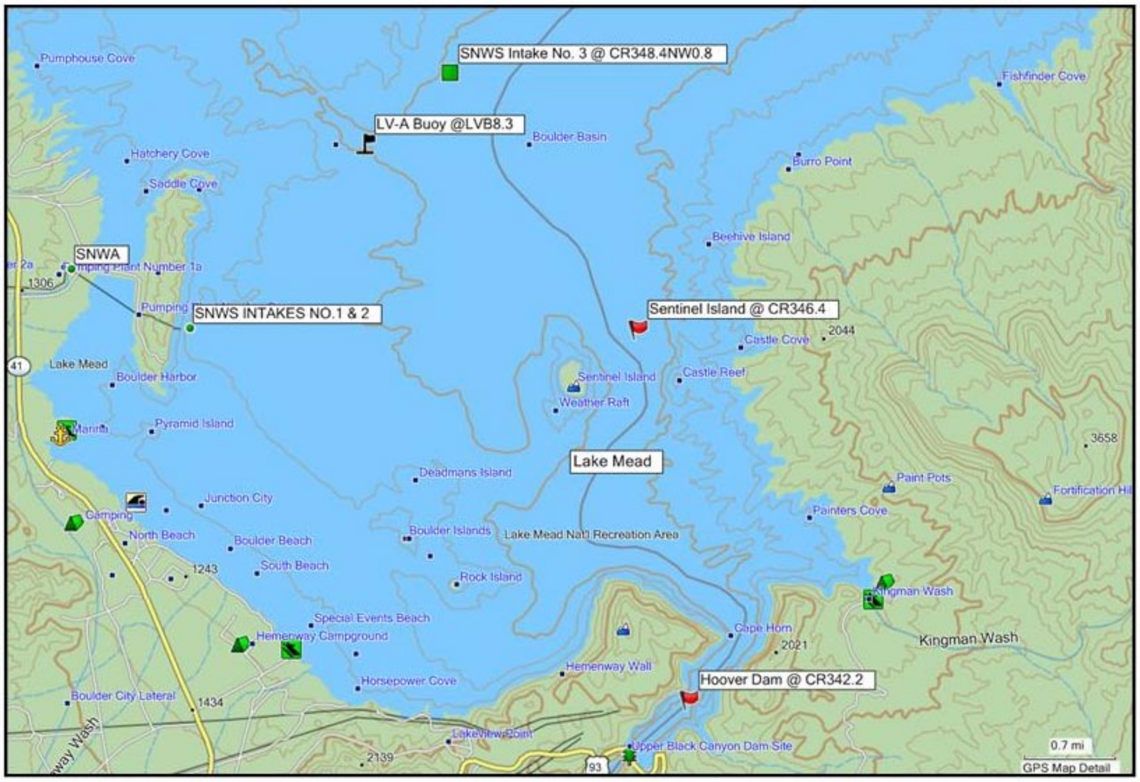

Figure 1. Location map of Boulder Basin, Lake Mead, Nevada. Sampling stations annotated on the map include SNWS site identifiers.

Methods and Materials

Velocity measurements were collected using a 300 kHz Teledyne/RD Instruments Workhorse ADCP. Water quality profiles were collected by SNWA personnel using a Eureka® Manta™ water quality multi-probe. Sampling sites for velocity profiling were located using SNWA's Trimble® global positioning system (GPS).

Water Quality Profiles

Water quality (WQ) profiles were measured concurrently with ADCP data at all sites visited. SNWS technicians were responsible for probe calibration, data collection, and processing. The following parameters were sampled: temperature, specific conductance, dissolved oxygen, pH, and turbidity. Data were collected at 1 meter depth intervals through the thermocline, then every 2 to 5 meters in the hypolimnion. WQ profile data presented in this report were reviewed and approved by SNWS technicians. When available, WQ profiles collected in Las Vegas Bay were used to determine the location of the Las Vegas Wash (LVW) interflow. These profiles were typically collected within two or three days of the

ADCP data collection. As a result, it is possible that the elevation of the LVW interflow might be slightly different than during our field visits.

ADCP Measurements

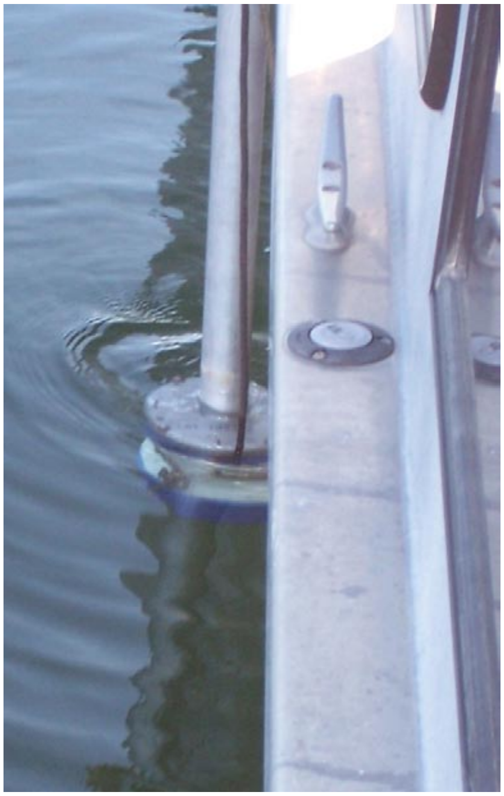

Figure 2. 300 kHz Workhorse ADCP mounted to the gunwale.

Velocity profile data were collected using an RD Instruments ADCP, operated from a tethered or drifting boat (figure 2). The ADCP used for this project was a 300 kHz Workhorse direct-read system which is well suited for this deep water application. The ADCP uses the Doppler shift principle to measure velocities along four acoustic beams projected downward below the boat. The instrument transmits precise acoustic pulses (called pings) and then listens for backscattered acoustic signals reflected from scatterers in the water column (e.g., organic or inorganic particles). The frequency change of the Doppler-shifted backscattered signal is proportional to the velocity of the scattering particles (which are usually moving at the same speed as the water). The ADCP receives and processes the backscatter signals. Each reflected signal is separated from the next by a fixed time. The reflected signals are used to compute velocities from uniformly spaced volumes commonly referred to as depth cells. The four acoustic beams are positioned 90E apart and are angled 20E from vertical. Trigonometric relationships for the acoustic beam configuration are used to resolve the three-dimensional velocity components for each depth layer. Velocities reported by the instrument are the resultant of velocities measured along each of four acoustic beams, rather than a measurement at a single point beneath the instrument. As a result, the accuracy of this measurement technique depends on the homogeneity of horizontal currents in layers of constant depth. In other words, the velocities detected by each beam must be similar in both magnitude and direction for each beam. Typically, horizontal homogeneity of currents in oceans, rivers, and lakes is a reasonable assumption. Care must be taken when collecting near-field ADCP measurements at intake structures because they can create non-homogeneous velocity fields.

For this project, the ADCP was configured to profile the water column 3 meter depth cells, or bins, yielding a velocity profile from about 5 meters below the water surface to about 8 meters above the reservoir bottom. Velocities cannot be measured near the surface because the transducer must be submerged and there is a time delay between transmit and receive modes of operation. This unmeasured depth is called the blanking distance and is usually 3 to 5 meters deep relative to the water surface. Likewise, velocities cannot be measured near the bottom (approximately the last 6 to 10 percent of the depth) due to a phenomenon called side-lobe interference. Side-lobe interference occurs when a lobe of secondary acoustic energy reflects off the bottom and interferes with backscatter echoes coming from depth cells close to the bottom. Side lobe interference was not an issue for this project because the currents of interest were not in this zone of interference.

Three orthogonal components of velocity (x, y, z) are measured by the ADCP; an internal compass allows the velocities to be referenced to an 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 depth where each beam hit the bottom. Velocity profiling from a moving boat requires dedicated bottom tracking pings to track the boat motion relative to the reservoir bottom using the same Doppler shift technique that is used to measure water velocity. Bottom tracking allows the water velocity measurements to be corrected to remove the boat's velocity from the current velocity, and permits tracking the position of the instrument throughout the transect. For this project, data at the Intake No. 3 site were collected while drifting. When winds caused the boat's drift speed to exceed water velocity, we collected a supplementary data set while moored to a nearby buoy at LVB8.3. Mooring allowed the collection of higher quality current measurements during windy conditions.

The ADCP configuration settings and commands used for this project are listed in the appendix. The most notable difference from a typical ADCP configuration was the use of the narrow bandwidth processing instead of broadband. The narrow bandwidth processing (WB1 command) was required to gain extended profiling range in the deep and low backscatter water at the Intake No. 3 site. While narrow bandwidth processing allows the ADCP to profile deeper, the consequence is that the standard deviation of a velocity measurement is increased by as much as 2.5 times that of a broadband measurement. This limitation was overcome by collecting several hundred profiles at the site to compute a mean velocity profile. According to PlanADCP version 2.04, which models ADCP performance for ideal conditions, velocity measurement would have an uncertainty (standard error) of ±0.37 cm/sec for an average of 500 ensembles. A listing of the PlanADCP output can be found in the appendix.

A laptop computer was used to configure the ADCP, control data collection, and store data. A GPS receiver was connected to the laptop computer so continuous

GPS positions were recorded simultaneously with the velocity data. Differentially corrected GPS positions were stored in the ADCP data files.

Field Data Collection

A total of 12 field visits were made between June 21, 2007 and August 26, 2009. A typical field visit included collecting ADCP and water quality profile data at the new intake location (CR348.4NW0.8), the SNWS intake near Saddle Island, and at Hoover Dam (CR342.5). If windy weather precluded the collection of high quality ADCP data at the Intake No. 3 site, data were collected while moored to Buoy LV-A located at LVB8.3. Table 2 summarizes the field visits covered in this report.

Table 2. Summary of data collection field trips to Lake Mead, Nevada.

Date	Lake Mead WSEL (ft)	Depth to new Intake El. 860 (ft)	Weather conditions and comments
06/21/07	1114.1	254	Clear, hot, and a slight breeze. Poor data quality
08/29/07	1111.9	252	Clear, warm and calm. Used new long-range configuration
11/30/07	1111.2	251	Clear, cool and windy, waves, noisy ADCP data
01/03/08	1114.9	255	Partly cloudy, cool, and calm
03/10/08	1117.8	258	After high flow test*. Clear, warm, and calm
03/11/08	1117.9	258	After high flow test*. Clear, warm, and calm
05/28/08	1107.4	248	Clear, warm, and windy
07/29/08	1104.6	245	Windy and wavy conditions, noisy ADCP data
09/18/08	1105.2	245	Clear, cool, and calm
12/04/08	1107.4	248	Partly cloudy, cool, and breezy
03/19/09	1109.7	250	Overcast, warm, and calm
06/04/09	1096.6	237	Cloudy, warm and breezy
08/26/09	1093.9	234	Clear, hot, and calm

*High flow test was an experimental release from Glen Canyon Dam, of approximately 41,500 ft^3/sec, for a maximum duration of 60 hours conducted from March 5 - 7, 2008.

Reservoir Currents Measured at Intake No. 3 (CR348.4NW0.8)

ADCP data collected at the Intake No. 3 site for the 12 field trips are summarized in table 3. Figures containing plots of velocity and water quality profiles for all field visits are in the appendix. Likewise, the appendix contains velocity data in tabular form.

On days when the wind made data collection at the Intake No. 3 site difficult, supplementary data were collected while moored to buoy LV-A (LVB8.3). LVB8.3 is about 0.9 miles to the southwest (215°) from Intake No. 3. When available, LVB8.3 velocities measured at the intake depth (El. 860) are included in table 4. On windy days, velocities collected at LVB8.3 are of higher quality because the boat speed was minimal when compared to boat speed while drifting with the wind. In table 3, bold italicized velocity directions are instances when water is moving NE and may transport Las Vegas Wash water toward Intake No. 3. However, with the exception of March 19, 2009, Boulder Basin was strongly stratified and the LVW interflow was located above the hypolimnion and would not be withdrawn by Intake No. 3.

Table 3. Summary of velocity measured at El. 860 at the Intake No. 3 site (CR348.4NW0.8). Velocity data in parentheses were collected while moored to Buoy LV-A (at LVB8.3). Bold velocity directions are instances when water is moving NE and may convey Las Vegas Wash water toward Intake No. 3.

Date	**Lake Mead WSEL (ft)**	**Depth to Intake El. 860 (ft)**	**Vmag (cm/sec)**	**Vdir (° from N)**	**Comments**
06/21/07	1114.1	254	n/a	n/a	Poor data quality characterized by large error velocity.
08/29/07	1111.9	252	1.3	**72.4**	New long-range ADCP configuration file used, Good data quality
11/30/07	1111.2	251	2.7	120	Wind from SE, Noisy data
01/03/08	1114.9	255	1.8	180	Good data quality
03/10/08	1117.8	258	0.8	230	High flow test, Good data quality
03/11/08	1117.9	258	1.6	211	High flow test, Good data quality
05/28/08	1107.4	248	1.5 (1.2)	288 **(67)**	Wind from SW, drifting
07/29/08	1104.6	245	1.6 (9.7)	347 (116)	Wind from E, drifting
09/18/08	1105.2	245	0.9	188	Good data quality
12/04/08	1107.4	248	0.3 (0.9)	83 (132)	Wind from NW, drifting
03/19/09	1109.7	250	2.6	**6**	Good data quality
06/04/09	1096.6	237	1.3 (5.3)	**33** (103)	Wind from NW, drifting
08/26/09	1093.9	234	0.7	198	Clear, hot, and calm

Las Vegas Wash Interflow

The fate and transport of Las Vegas Wash interflows is of special concern when selecting the location of Intake No. 3 because the interflow transports treated wastewater and contaminated groundwater into Lake Mead's Boulder Basin. Consequently, SNWS operators want to prevent the withdrawal of LVW water at

Intake No. 3. Two important factors in preventing this situation are the depth of the interflow with respect to the intake's withdrawal zone and the direction the interflow is moving. A comparison of seasonal LVW interflow depths (figure 3) shows that during this study the LVW interflows were located close to the minimum depth range reported by LaBounty and Horn [1]. A detailed analysis of this observation is beyond the scope of this project, but LaBounty and Horn reported that the interflow is forced higher in the water column because of higher inflows (thermal inertia) and warmer water temperatures caused by tertiary treatment, along with the channelization of Las Vegas Wash (shorter travel time). It is also plausible that the recent drought and lower water levels in Lake Mead may have altered the thickness of the mixed surface layer (epilimnion). LaBounty's data were collected during 1991 to1996 when the reservoir was nearly full and the intake study was conducted during a period of drought when the reservoir level was lower by more than 20 meters.

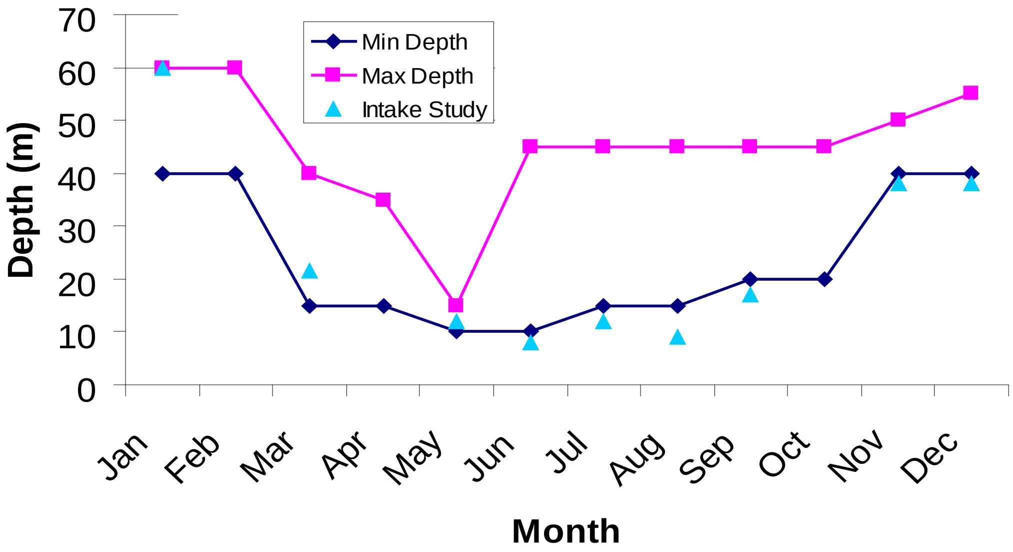

Figure 3. Comparison of LaBounty and Horn's LVW interflow depths with those observed during this intake study. It is important to note that LaBounty's data were from 1991 to1996 when the reservoir was nearly full and the intake study was conducted when the reservoir was lower by more than 20 meters.

Table 4 contains a summary of reservoir currents measured at the depth of the LVW interflow at the new intake sampling site (CR348.4NW0.8). The depth of the LVW interflow was determined using SNWS water quality profiles collected in Las Vegas Bay, typically at LVB6.7 or LVB 4.15. This approach assumes LVW interflow has achieved equilibrium with the ambient water and is representative of the equilibrium depth in Boulder Basin. Data in table 4 is intended to illustrate the potential for LVW water to be transported toward the new intake site; currents at the interflow depth which could move LVW water toward Intake No. 3 are shaded. It is important to note that currents in the epilimnion are primarily generated by the wind and LVW water located within the epilimnion would not be available for withdrawal by Intake No. 3 even if they are moving in that direction. Likewise, when the LVW interflow is positioned in the hypolimnion, currents are typically directed toward Black Canyon and Hoover Dam which may preclude LVW water from flowing toward Intake No. 3. This observation is supported by SNWS water quality records that show LVW water is withdrawn through intakes No. 1 and No. 2 when the LVW interflow depth is coincident with these intake's withdrawal zones.

Table 4. Summary of reservoir currents at the LVW Wash Interflow depth for 12 field visits. These current data were measured at the new intake sampling site (CR348.4NW0.8). Shaded data are reservoir currents that could transport LVW water toward the new intake location, but the LVW interflow is at an elevation well above the intake at El. 860 ft.

Date	Lake Mead WSEL (ft)	V_{mag} (cm/sec)	V_{dir} (° from N)	LVW Interflow Depth, layer
06/21/07	1114.1	1.9	340	20 ft, epilimnion
08/29/07	1112.0	2.5	223	20 ft, epilimnion
11/30/07	1111.1	2.5	33	125 ft, top of thermocline
01/03/08	1114.9	1.9	148	164 ft, epilimnion
03/10/08	1117.8	4.7	162	52 ft, hypolimnion
05/28/08	1107.5	4.4	0	39 ft, epilimnion
07/29/08	1104.7	8.1	293	39 ft, top of thermocline
09/18/08	1105.4	1.2	136	56 ft, top of thermocline
12/04/08	1107.5	3.2	213	125 ft, top of thermocline
03/19/09	1109.7	1.5	208	89 ft, hypolimnion
06/04/09	1096.7	1.7	14	33 ft, top of thermocline
08/26/09	1094.0	2.9	61	39 ft, top of thermocline

Hoover Dam Forebay Currents

When time and conditions permitted, ADCP data were collected in Hoover Dam's forebay at the SNWS sampling site located about 0.5 miles up lake at CR342.2. Data collection at this location is useful to describe the withdrawal zone characteristics which are an important factor in the hypolimnetic currents. Current measurements for eight field visits are summarized in table 5. These hypolimnetic currents were measured at the Intake No. 3 El. 860 and are very repeatable in both magnitude and direction. Variability in current magnitudes is likely attributed to near-field influences related to Hoover Dam powerplant releases and the flow distribution between the Nevada and Arizona intake towers. As shown in figure 4, current direction is nearly perpendicular to Hoover Dam, which is about 228° from north (corrected for the local magnetic declination).

When Hoover Dam currents at El. 860 ft are compared to those at Intake No. 3 (in table 3) they are larger in magnitude which is to be expected in a narrow cross section like Black Canyon. It is important to note that reservoir currents generated by Hoover releases play an important role in drawing LVW inflow toward Black Canyon and away from the Intake No. 3 site.

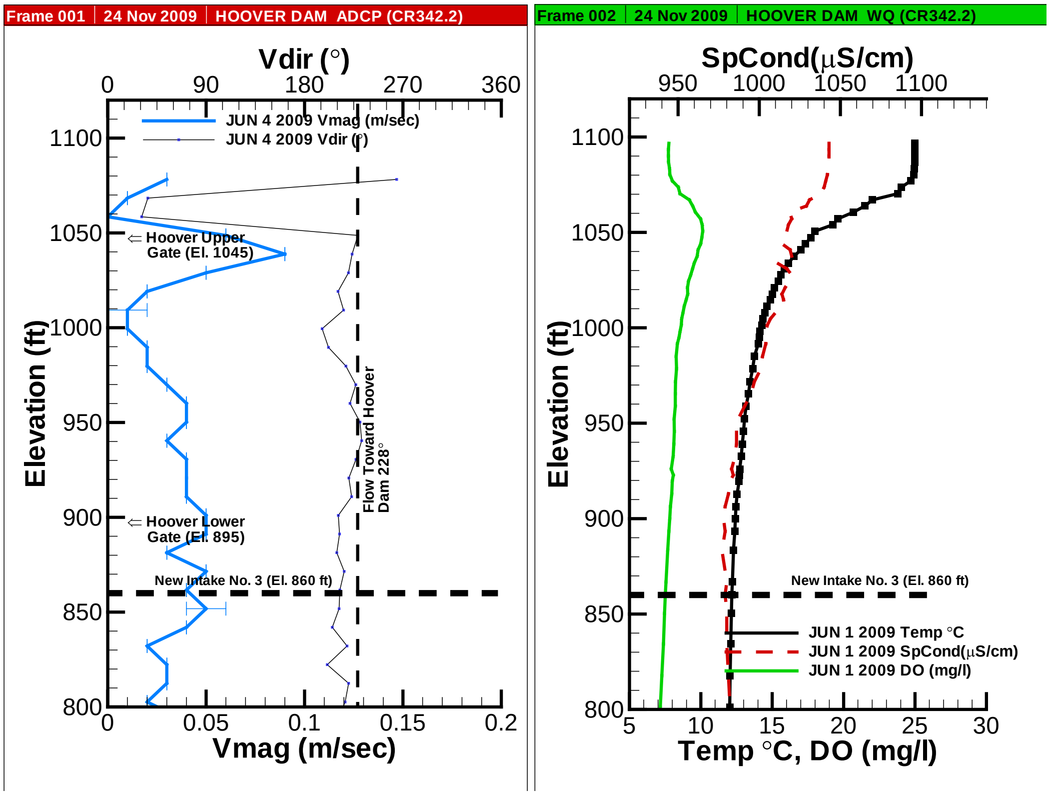

Figure 4. Typical ADCP and water quality profiles collected at Hoover Dam on June 4 and June 1, 2009, respectively. With the exception of wind driven currents in the epilimnion, ADCP data show that currents in the thermocline and hypolimnion are moving toward Hoover Dam and peak velocities coincide with the intake tower gate elevations.

Table 5. Summary of hypolimnetic currents in the forebay to Hoover Dam. These currents were measured at the elevation of Intake No. 3 (el 860 ft).

Date	Depth to Intake No. 3 (ft)	Vmag (cm/sec)	Vdir (° from N)	Elevation (ft)
08/29/07	254.82	4.4	238	857
03/10/08	244.82	1.6	215	865
05/28/08	244.85	2.4	154	863
07/29/08	244.91	2.6	245	860
09/18/08	244.95	2.9	214	860
12/04/08	244.82	2.8	215	863
06/04/09	235.04	4.3	213	862
08/26/09	235.10	1.9	228	859

SNWS Intake Currents

A previous current measurement study [2] at SNWS Intake No. 1documented the selective withdrawal characteristics of the intake. One conclusion from that study was that the currents were slow which required collecting data while stationary to obtain the highest quality ADCP data. Since then, Intake No. 2 construction was completed with an intake elevation of 992 ft. In July 2004, Intake No. 1 was modified with a steel extension to lower the intake to El. 1000 ft. While there has been significant modification to the intakes No. 1 and No. 2, the scope of work for this project did not include detailed velocity data collection near these intakes. However, when time and weather conditions permitted, ADCP data were collected near the two SNWS Intakes at Saddle Island. All ADCP measurements at this location were collected while drifting. As a result, the ADCP data quality was highly dependent on the wind conditions. Table 6 contains a summary of the currents measured at El. 1000 ft near the SNWS intakes for ten field visits. These primarily hypolimnetic currents were measured at the average withdrawal elevation of intakes No. 1 and No. 2. These data are repeatable in magnitude, but not in direction. Variability in current direction is likely attributed to influences from Hoover Dam releases and/or directional bias that occur when ADCP data are collected while drifting past the intake. For example, if the boat drifts past the intake from north to south, the velocity direction will transition from southwest to northwest and the average direction will be around 270° from north. On the other hand, if the boat is stationary north of the intakes the current direction will be in a southwesterly direction. Another important factor affecting currents near the Saddle Island intakes that was not analyzed is the affects of Hoover releases and SNWS pumping rates on near-field intake currents.

Table 6. Summary of currents measured at the SNWS Intakes (El. 1000 ft) for ten field visits. Current data were measured while drifting near the SNWS Intake sampling site

Date	Lake Mead WSEL (ft)	Depth to Intake El. 1000 (ft)	V_{mag} (cm/sec)	V_{dir} (° from N)	LVW Interflow Depth, layer
06/21/07	1114.1	114.1	2.3	193	20 ft, epilimnion
01/30/08	1114.9	114.9	2.5	300	164 ft, epilimnion
03/10/08	1117.8	117.8	1.3	49	52 ft, hypolimnion
05/28/08	1107.5	107.5	1.3	226	39 ft, epilimnion
07/29/08	1104.7	104.7	0.5	120	39 ft, top of thermocline
09/18/08	1105.4	105.4	1.2	242	56 ft, top of thermocline
12/04/08	1107.5	107.5	1.6	89	125 ft, top of thermocline
03/19/09	1109.7	109.7	1.7	288	89 ft, hypolimnion
06/04/09	1096.7	96.7	0.4	310	33 ft, top of thermocline
08/26/09	1094.0	94.0	1.5	202	39 ft, top of thermocline

Selective Withdrawal Modeling

To estimate release water quality parameters from stratified reservoirs, the U.S. Army Corps of Engineers developed SELECT, a one-dimensional selective withdrawal spreadsheet model. This modeling tool was developed to assist reservoir operators with the day-to-day operations of a dam equipped with a selective withdrawal structure. For this project, SELECT was used to determine the withdrawal characteristics for the proposed SNWS Intake No. 3. Intake No.3 will be a deep water intake and the elevation of the upper limit of withdrawal is of primary concern because the LVW interflow is usually positioned above the proposed intake elevation (860 ft). Application of the SELECT model was used to predict the seasonal withdrawal characteristics of Intake No. 3 and to estimate water quality characteristics of the raw water withdrawals.

For this project, SELECT Version 1.0 Beta [3] was used for all selective withdrawal modeling. SELECT was developed to provide the project operators with an estimate of the release water quality from a stratified reservoir through an intake structure with several intake ports. The user must supply the following information: Water surface and reservoir bottom elevations; outlet port elevation, discharge, and withdrawal angle; and local water quality profile. Once these data have been entered, the spreadsheet automatically updates the estimates of release water quality for temperature and up to four other water quality parameters. For this project, temperature, specific conductance, dissolved oxygen, and pH were modeled.

In SELECT, withdrawal ports (gates) can be described as a point sink. The withdrawal port is described by the centerline elevation of the intake; in this case, El. 860 ft was used. Another model setup parameter is the port withdrawal angle which describes the intakes orientation with respect to underwater obstructions or local bathymetry. Intake No. 3 was modeled using an 180^{o} withdrawal angle because the higher ground located to the northwest only allows water from Boulder Basin to be withdrawn. However, under certain conditions it is feasible that Las Vegas Wash inflow would move down the channel thalweg to be pulled up lake toward Intake No. 3. Whether this condition occurs will depend on currents generated by other hypolimnetic currents in Boulder Basin such as Colorado River interflows, Hoover Dam releases, and other municipal water supply withdrawals near Saddle Island.

For this project, SELECT was used to predict Intake No. 3 water quality for the 12 data sets collected for a wide range of reservoir stratification. The upper limit of the withdrawal zone was also used to see if it coincided with the LVW interflow.

SELECT Modeling Results

SELECT modeling results for field visits spanning June 2007 to August 2009 are summarized in Table 7. These data show that Intake No. 3 withdrawals are typically below the LVW interflow layer. This finding is important because it shows that for a wide range of thermal stratification the LVW interflow is inaccessible to Intake No. 3 withdrawals. An exception is January 2008 when the interflow and the upper limit of withdrawal were both at El. 918. While the intake withdrawal zone includes the LVW interflow, current measurements showed that the LVW interflow was moving toward Hoover Dam at about 2 cm/sec and was directed 150° from north. It is important to note that reservoir currents are variable and it is conceivable that the LVW interflow could move toward the new intake site. However, it would be a rare circumstance and likely short lived considering the influence of Hoover Dam releases on hypolimnetic currents.

Table 7. SELECT Model predictions for the proposed SNWS Intake No.3 for reservoir water quality conditions from June 2007 to August 2009. SELECT results for Jan 30, 2008 indicate a potential entrainment of the LVW interflow if reservoir currents are moving the interflow to the northeast.

Date	Lake Mead WSEL (ft	LVW Interflow Elev. (ft)	Intake No.3 Upper Limit of Withdrawal Elev. (ft)	Temp. (°C)	Conductivity (µS/cm)	Dissolved Oxygen (mg/l)	pH
06/21/07	1114.1	1094	935	11.1	998	8.6	8.1
08/29/07	1112.0	1092	927	11.2	978	7.8	8.3
11/30/07	1111.1	986	920	11.4	986	7.9	8.1
01/03/08	1114.9	918	919	11.5	979	6.8	8.0
03/11/08	1118.0	987	936	11.3	1011	8.0	8.4
05/28/08	1107.5	1068	938	11.2	990	8.7	8.3
07/28/08	1104.7	1065	926	11.5	994	8.7	8.1
09/15/08	1105.4	1059	922	11.7	985	8.0	8.1
12/04/08	1107.4	983	916	11.8	996	7.1	8.0
03/19/09	1109.7	1028	939	11.9	979	7.8	8.0
06/04/09	1096.7	1067	932	12.2	970	7.5	8.3
08/26/09	1094.0	1061	923	12.4	948	8.1	8.1

Discussion

Hydrodynamics in a large reservoir like Lake Mead can be very complex and cannot be completely described by collecting 12 snap shots of the conditions at the new intake site. There are several factors which affect reservoir currents and a basic understanding of these factors is needed to interpret data presented in this report. Some important concepts and observations are summarized below:

Lake Mead's Boulder Basin is thermally stratified for much of the year, and the LVW inflow will reach equilibrium at an elevation where its density equals that of the ambient water density in Boulder Basin. During periods of thermal stratification, the LVW interflow is usually located at the interface of the epilimnion and thermocline. The thermocline's vertical position varies with seasonal warming and cooling. The only time the top of the thermocline (interflow) will encroach on Intake No. 3 (El. 860) is during the winter months when reservoir stratification is very weak or when Boulder Basin becomes isothermal.

Because the LVW interflow is often located near the bottom of the epilimnion it is affected by wind-generated currents. Wind creates currents that can mix the epilimnion which will dilute and transport the LVW inflows throughout Boulder Basin. Sustained wind events will create a circulation within the epilimnion and the surface currents will normally be in the direction of the prevailing winds. In Boulder Basin the prevailing wind directions are NW/SE and NE/SW (using meteorological convention, winds are named for the direction ***from*** which they are blowing). For example, a NE wind will create a surface current toward the SW and a NE current in the lower portion of the epilimnion which could transport LVW water toward Intake No. 3. It is important to note that the lower epilimnetic current direction is often altered by local bathymetric features such as islands or submerged ridges.

Velocities measured near Intake No. 3 can be influenced by peaking power operations at Hoover Dam, withdrawals by SNWS intakes No. 1 and No. 2, Colorado River inflow, reservoir circulation patterns, and internal waves. However, Hoover Dam releases are most likely to have the greatest influence on currents at Intake No. 3. For conditions when the LVW interflow is located near El. 860 and when Intake No. 3 is operating at full capacity (1860 ft^3/sec), it is possible that the intake may create a withdrawal zone capable of drawing LVW water toward the intake, especially when Hoover Dam releases are below 2000 ft^3/sec. Typically, Hoover releases in this range occur during a 4 to 5 hour period each day in the winter months.

Reservoir currents at Intake No. 3 with a NE direction (30 to 60°) and coincident with the intake's withdrawal zone are of particular concern because this current condition could potentially transport Las Vegas Wash interflows toward Intake

No. 3 location. However, when LVW water is being transported toward Intake No. 3 it is important to recognize that it is uncommon for LVW interflow to be vertically located in the hypolimnion and available for withdrawal through Intake No. 3. When it is, hypolimnetic currents produced by the Hoover Dam releases are usually strong enough to draw the LVW interflow toward Black Canyon.

Care must be taken to compare ADCP velocity data with water quality profiles in the vicinity to determine if water moving toward the new intake is of good or poor quality. ADCP data presented in this report are combined with WQ profiles to easily make this comparison. If the LVW interflow is present at the sampling site it is easily identified by its high conductivity.

Like the LVW interflow, the Colorado River inflow to Lake Mead reaches equilibrium with the ambient water in Boulder Basin. Typically, river inflow is located in the thermocline or hypolimnion where it will track the historic river channel. At the new intake site the Colorado River interflow will normally create a southwesterly current past the site. When the Colorado River and LVW interflows are near the same elevation the river inflow will move the LVW interflow to the southwest. When the Colorado River is a density current (flowing along the bottom) or an interflow located above Intake No. 3, it could set up a secondary circulation that would transport LVW water toward the new intake site. This current forms to feed water to the interfacial shear mixing zone created by the river's interflow. This condition was not observed during the March 2008 high-flow experiment when flood releases from Glen Canyon Dam created a stronger-than-normal density current in Boulder Basin.

Conclusions

An analysis of seasonal reservoir current and water quality profiles collected at the proposed Intake No. 3 site did not identify conditions where Las Vegas Wash water was available for withdrawal by the new intake. However, given the complex nature of reservoir density currents, and the limited data set, it is feasible that during periods of weak thermal stratification LVW interflows could be transported by hypolimnetic currents toward Intake No. 3. With Hoover Dam releases creating hypolimnetic currents toward Black Canyon, this condition would probably occur infrequently. However, SNWS project operators should closely monitor water quality at the intake site during winter months, and if the conditions warrant, be prepared to curtail or discontinue Intake No. 3 operations until the conditions improve. Provided Lake Mead's water surface elevation is sufficient to operate intakes No.1 and No.2, these intakes would likely have better water quality for this condition and, in such cases, should be used instead of Intake No. 3.

While it is a very remote possibility, reduced flow through the El. 895 intake gates on the Hoover intake towers (e.g. from trash rack blockage) would reduce the strong hypolimnetic current that draws the LVW interflow toward Black Canyon. For this type of operation, winter current circulation patterns in Boulder Basin would be dependent on Colorado River interflows which could create an uplake current that could transport hypolimnetic LVW water toward Intake No. 3. Again, this situation is limited to the winter months when thermal stratification is weak and the LVW interflow is located near El. 860.

In an earlier study of Las Vegas Wash inflows, Fisher and Smith [4] concluded that "misleading results may be obtained from brief observations limited to a particular time of day." The author acknowledges this limitation applies to this study, especially for currents and water quality measured in the epilimnion and thermocline which can be easily modified by seiches or other sources of internal waves. However, practicality and safety concerns limit intensive data collection to daylight hours, so it is important to consider this observation when interpreting data in this report and future data sets. It is possible that US Geological Survey monitoring data (ADCP and WQ profiles) at Sentinel Island may provide some insight into Boulder Basin hydrodynamics.

References

[1] LaBounty, J. F. and M. J. Horn, 1997. The influence of drainage from the Las Vegas Valley on the limnology of Boulder Basin, Lake Mead, Arizona-Nevada. Lake and Reserv. Manage. 13(2):95-108.

[2] Vermeyen, T. B., Acoustic Doppler Velocity Measurements Collected Near the Southern Nevada Water System Intake, Lake Mead, Nevada. Technical Report, Bureau of Reclamation, Technical Service Center, Denver Colorado. March 8, 2002.

[3] Schneider, M. L., S. C. Wilhelms, L. I. Yates, 2004. SELECT Version 1 Beta : A One-Dimensional Reservoir Selective Withdrawal Model Spreadsheet, US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, Mississippi 39180

[4] Fisher, H. B., and R. D. Smith, 1983. Observations of transport to surface waters from a plunging inflow to Lake Mead. Limnol. And Oceanog. 28(2): 258-272.

Appendix

Figures - Plots of ADCP and water quality data at CR348.4NW0.8

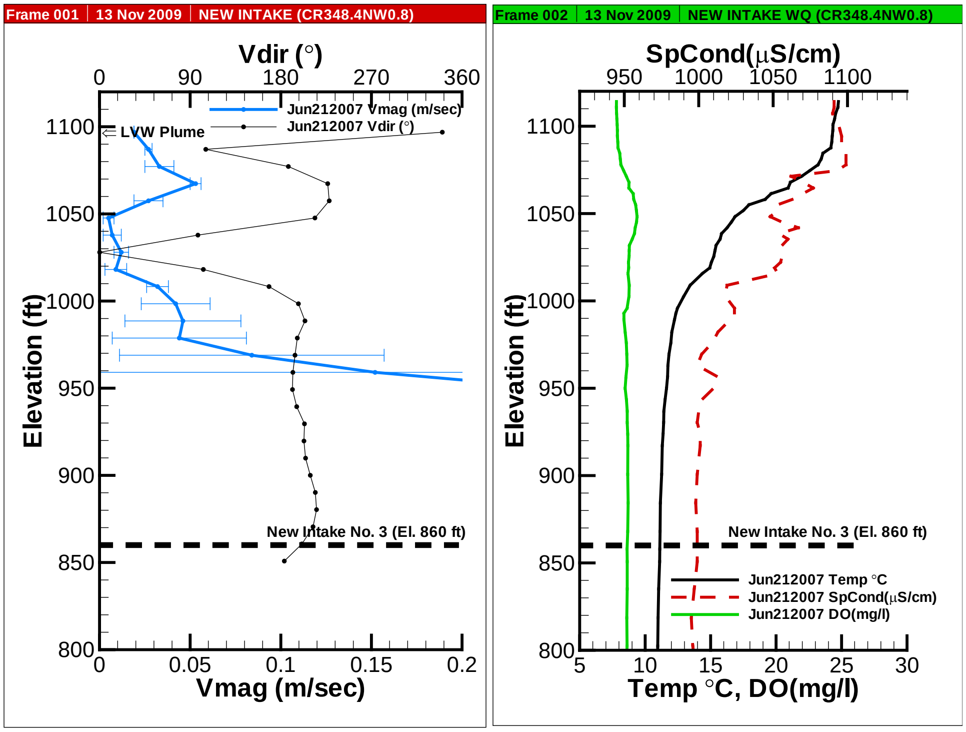

Figure A1 - Plots of ADCP and water quality data collected June 21, 2007. As indicated by the large error bars, velocity magnitude data below elevation 1010 are of poor quality.

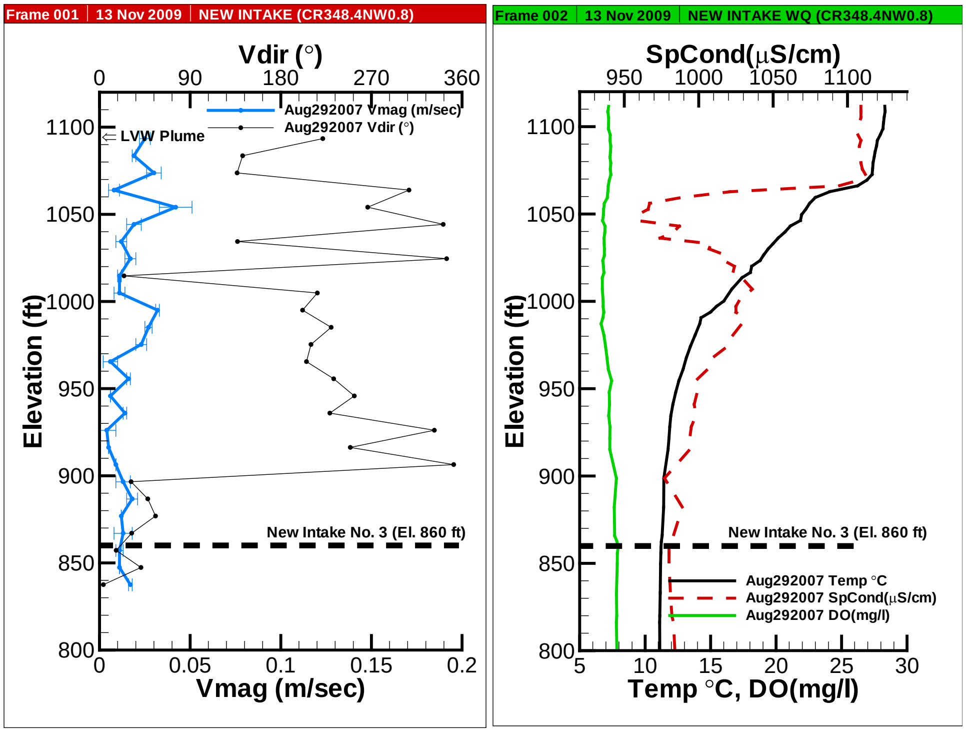

Figure A2 - Plots of ADCP and water quality data collected August 29, 2007

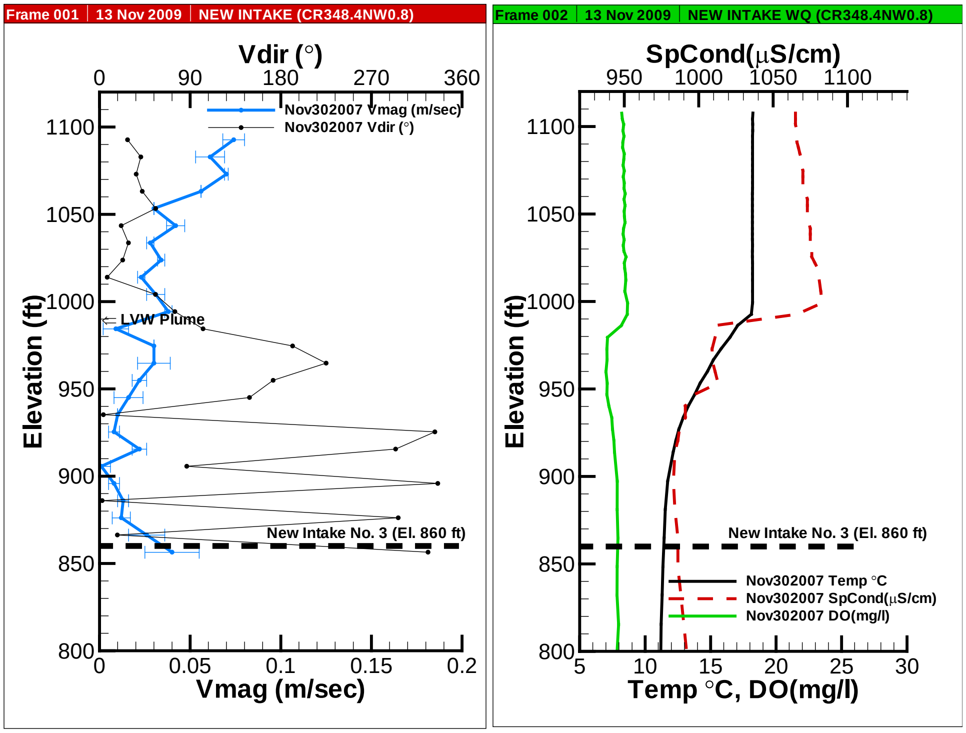

Figure A3 - Plots of ADCP and water quality data collected November 30, 2007

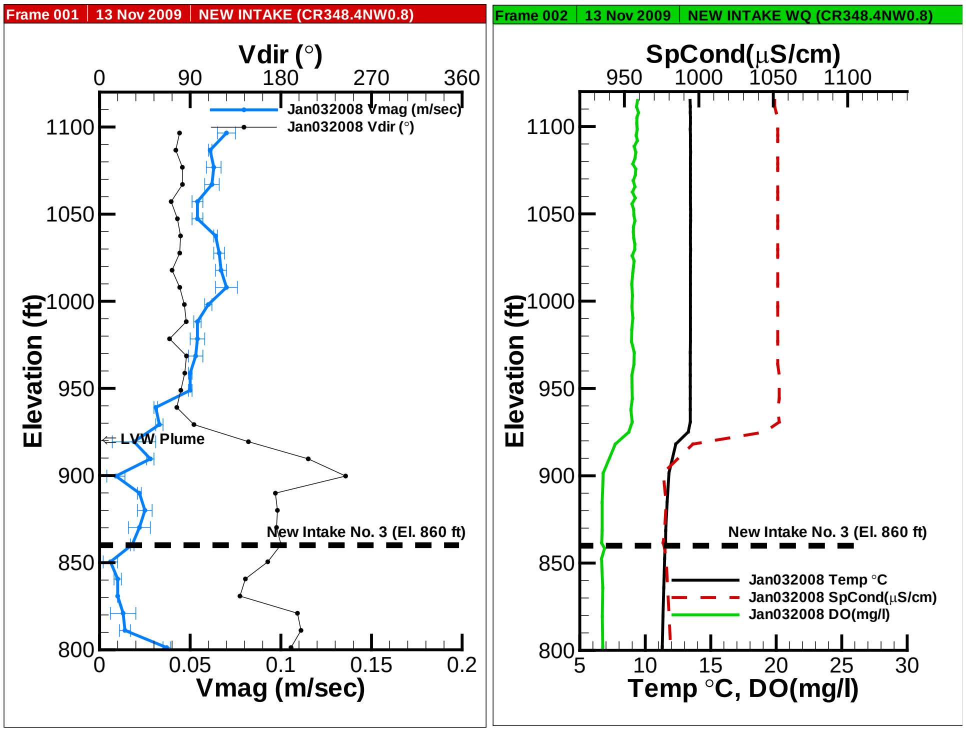

Figure A4 - Plots of ADCP and water quality data collected January 3, 2008. This data set was collected for a weakly stratified condition and the LVW plume was at El 920.

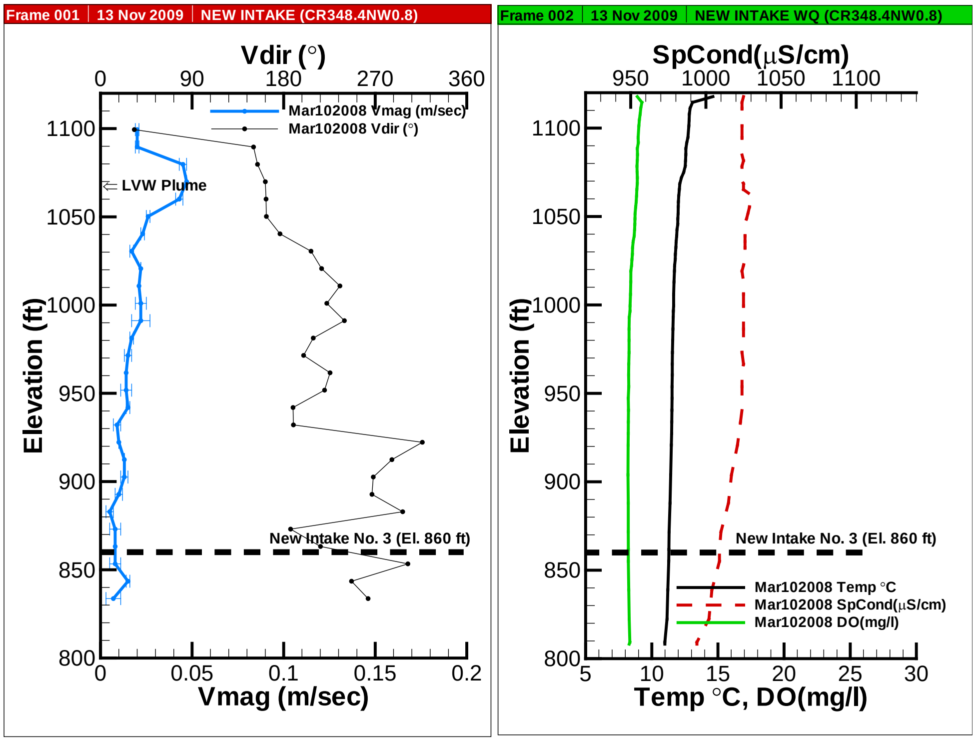

Figure A5 - Plots of ADCP and water quality data collected March 10, 2008 during the high flow release from Glen Canyon Dam.

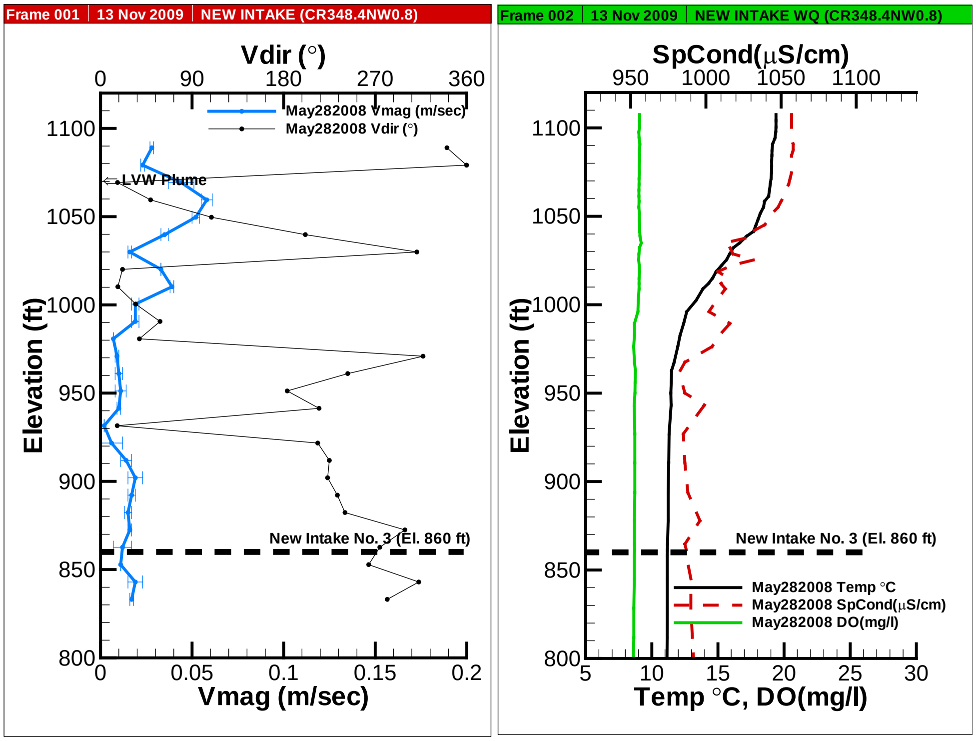

Figure A6 - Plots of ADCP and water quality data collected May 28, 2008

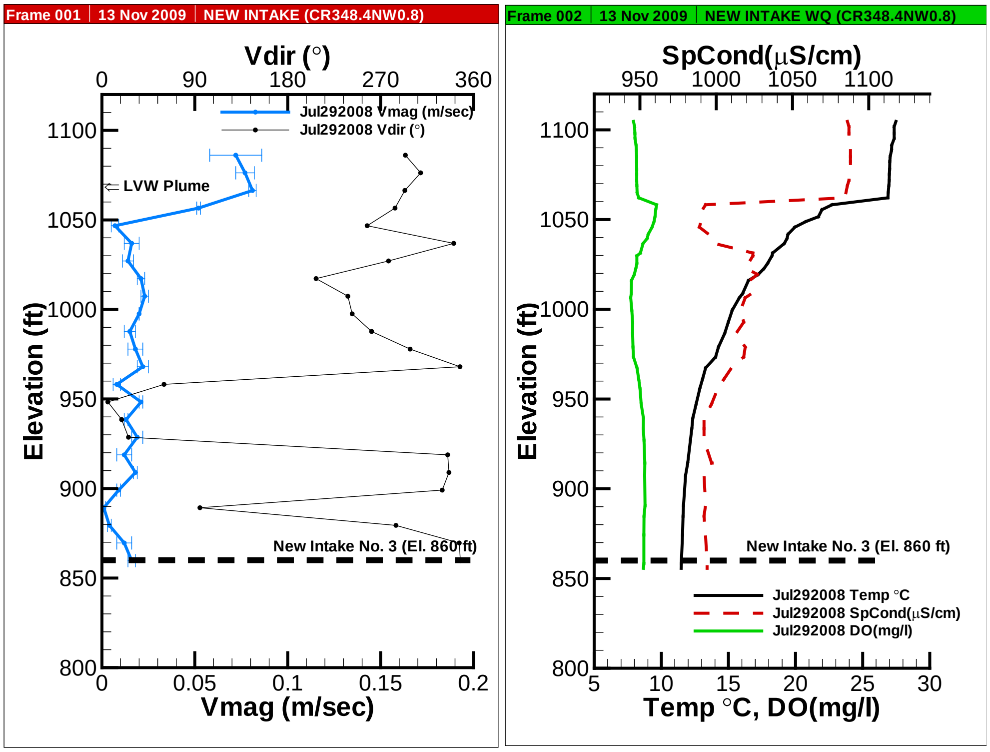

Figure A7 - Plots of ADCP and water quality data collected July 29, 2008

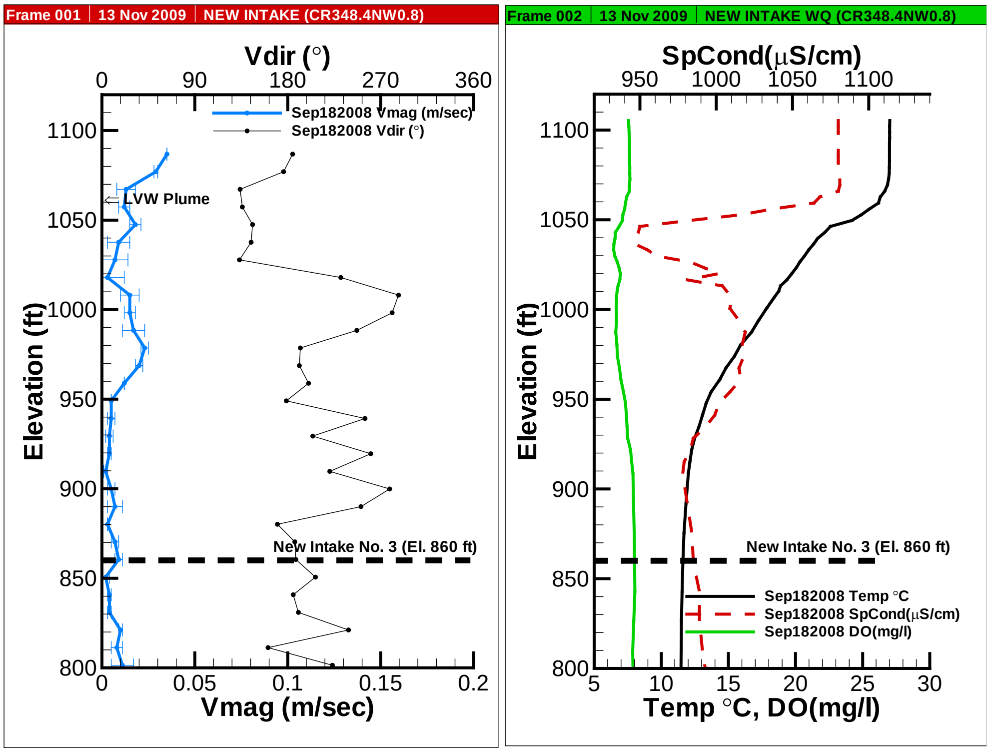

Figure A8 - Plots of ADCP and water quality data collected September 18, 2008. The low conductivity layer near El. 1040 is probably the Colorado R. interflow.

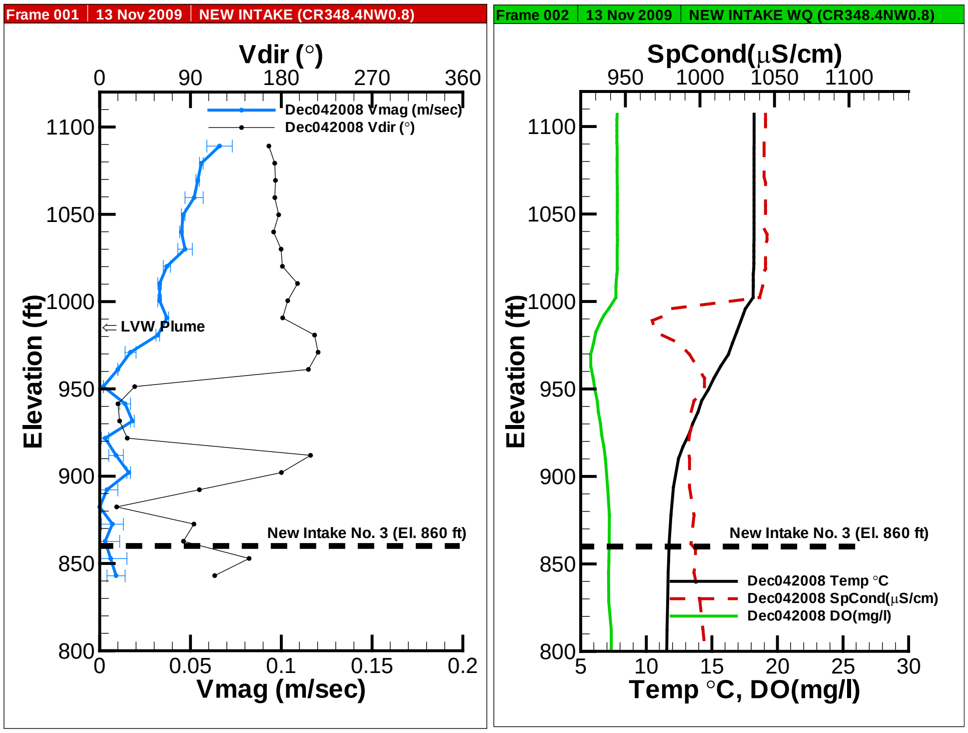

Figure A9 - Plots of ADCP and water quality data collected December 4, 2008.

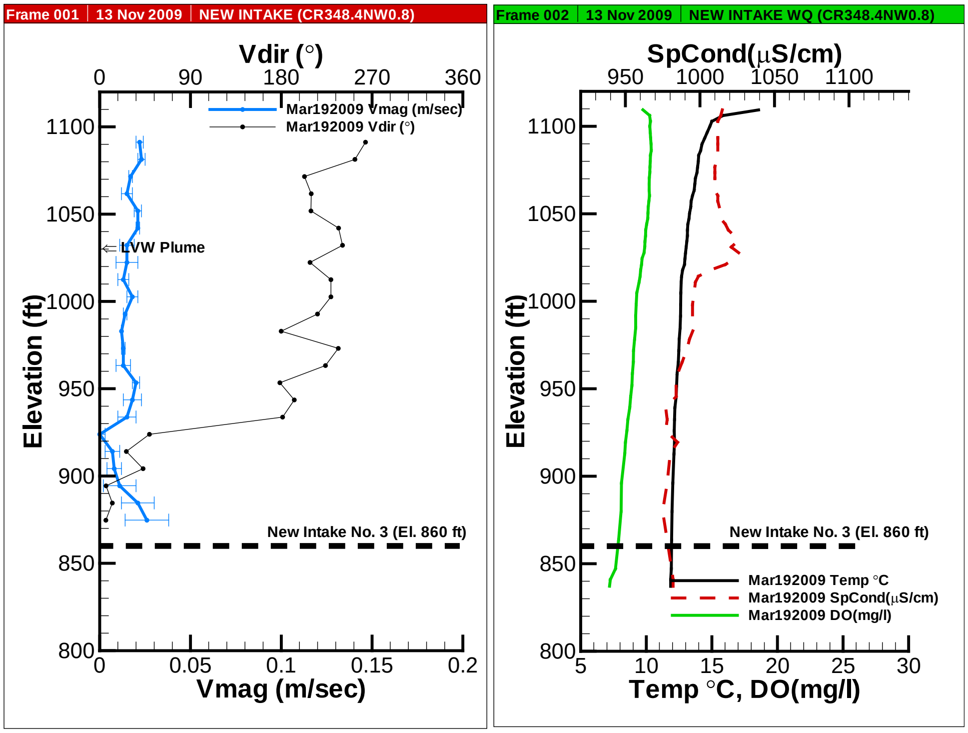

Figure A10 - Plots of ADCP and water quality data collected March 19, 2009. Currents below El. 920 could potentially transport LVW flows (if present) toward Intake No. 3.

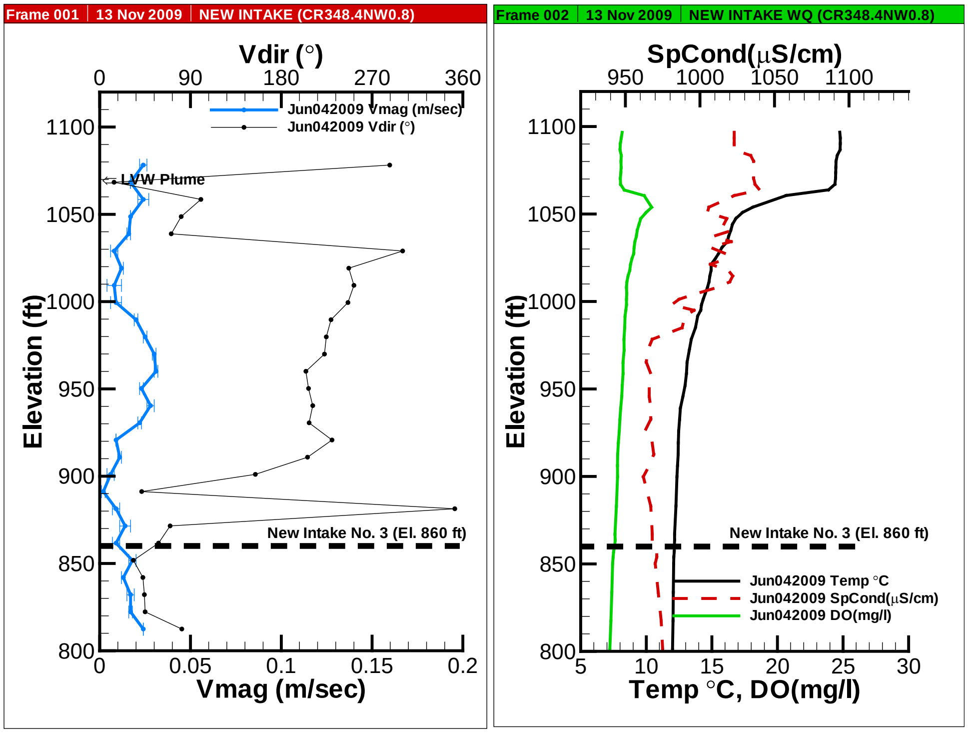

Figure A11 - Plots of ADCP and water quality data collected June 4, 2009.

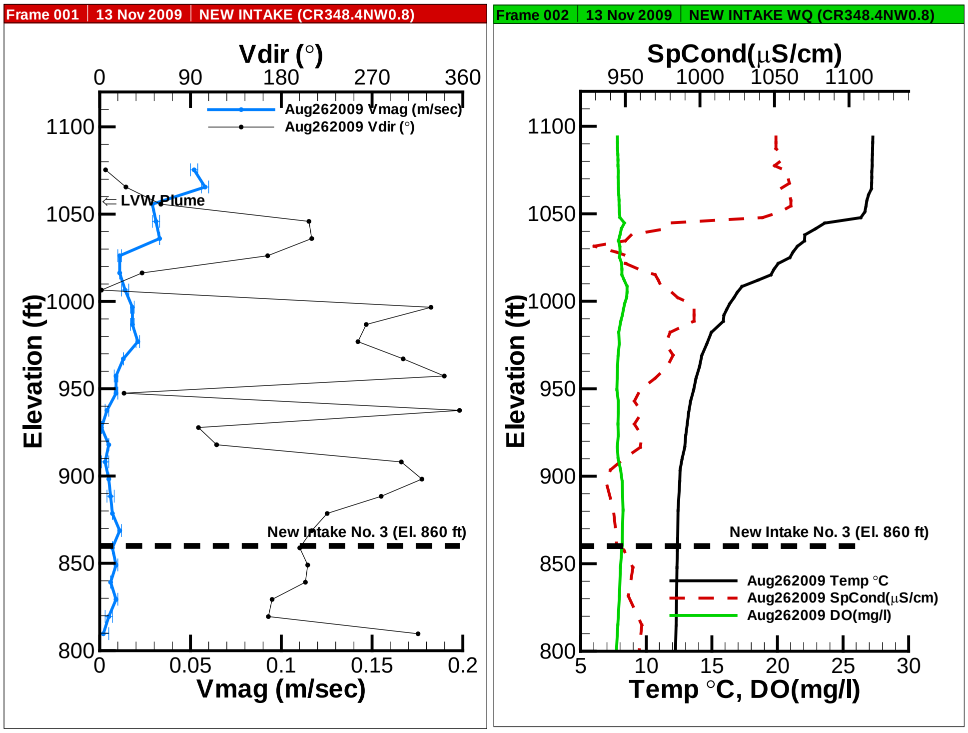

Figure A12 - Plots of ADCP and water quality data collected August 26, 2009.

Tables - ADCP Data collected at Intake No. 3

Tables A1 through A12 contain average ADCP data collected at CR348.2NW0.8. These data are both spatial and temporal averages because the time series data were collected while drifting. The table contains earth-referenced velocity components (East, North, Up, Error), percent good pings for each depth, and the elevation of the velocity reading.

The error velocity (Verror) is a data quality parameter that is a measure of the difference between two independent measurements of the vertical velocity component. RDI's velocity calculations assume that all the acoustic beams are sensing the same flow field. Error velocity evaluates how well this assumption is being met, providing a quantitative base for QA/QC at each depth layer of each ping. For this project, ADCP data were filtered such that Verrors greater than 10 cm/sec were excluded from the average velocity profile. When conditions are good for ADCP data collection very few data are filtered out. Conversely, when boat motion is excessive, a high percentage of the data are filtered out. Therefore, data collected on windy days will have lower percent good values.

According to RDI's user's manual, the Verror value has the following characteristics:

- Verror is a more sensitive data quality measure than is echo intensity.
- Verror provides an independent measure for evaluating data quality during analysis, peer review, or in a court of law.
- Verror helps reduce noise in average values by screening for non-uniformity caused by fish, turbulence, or eddy variability.
- Verror helps reduce data bias by detecting consistent obstructions from solid scatterers (structures, vessels, mooring lines, buoys, suspended instruments, etc.).
- Verror provides a quick and independent way to screen horizontal velocity (flow) variance.

List of Tables

Table A1 – June 21, 2007 ADCP Profile (average of 4100 ensembles). Shaded data are poor quality because the Verror values were too high. File=SNWS005R.000

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev(ft)
5.25	0.019	340.4	-0.006	0	100	1096.876
8.25	0.027	105.5	-0.007	0.002	100	1087.033
11.25	0.033	187.5	-0.005	0.008	100	1077.191
14.25	0.053	226.6	-0.006	-0.003	100	1067.348
17.25	0.027	228.1	-0.006	-0.008	100	1057.506
20.25	0.005	213.9	-0.006	-0.003	100	1047.663
23.25	0.007	97.7	-0.003	-0.005	100	1037.82
26.25	0.012	0.1	-0.003	-0.004	100	1027.978
29.25	0.009	103.1	-0.002	-0.006	100	1018.135
32.25	0.032	168.3	0	-0.006	100	1008.293
35.25	0.042	197.5	0.003	-0.019	100	998.4504
38.25	0.046	204	0.01	-0.032	100	988.6079
41.25	0.044	196.4	0.015	-0.037	100	978.7654
44.25	0.084	194.1	0.032	-0.073	100	968.9228
47.25	0.152	192	0.072	-0.161	100	959.0803
50.25	0.26	191.6	0.133	-0.25	100	949.2378
53.25	0.336	195.8	0.189	-0.303	100	939.3953
56.25	0.385	203.5	0.246	-0.353	100	929.5528
59.25	0.457	203	0.306	-0.402	100	919.7102
62.25	0.499	204.6	0.349	-0.455	100	909.8677
65.25	0.526	209.3	0.403	-0.457	100	900.0252
68.25	0.528	214.3	0.427	-0.481	100	890.1827
71.25	0.514	215.5	0.453	-0.455	100	880.3402
74.25	0.467	212	0.486	-0.435	100	870.4976
77.25	0.396	201	0.515	-0.467	94	860.6551
80.25	0.364	183.5	0.532	-0.453	53	850.8126

Table A2 – August 29, 2007 ADCP Profile (average of 400 ensembles).
File=LMXR003R.000

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev(ft)
5.67	0.025	221.7	0.004	-0.003	77	1093.398
8.67	0.019	142.1	0.001	0.001	82	1083.555
11.67	0.03	136.6	0.002	-0.004	80	1073.713
14.67	0.008	307.3	0	-0.003	83	1063.87
17.67	0.042	266.3	0.001	-0.009	84	1054.028
20.67	0.019	341.3	0.004	-0.004	83	1044.185
23.67	0.012	137	0.003	0.003	80	1034.343
26.67	0.017	344.7	0.004	-0.003	81	1024.5
29.67	0.011	24.3	0.004	0.001	83	1014.657
32.67	0.011	216.3	0.001	0.003	82	1004.815
35.67	0.032	201.6	-0.001	-0.001	85	994.9724
38.67	0.027	230	-0.002	-0.002	81	985.1299
41.67	0.023	210	0.003	-0.003	80	975.2874
44.67	0.006	205.5	0.004	-0.004	79	965.4449
47.67	0.016	232.5	0.005	-0.001	80	955.6024
50.67	0.006	253	0.003	0	84	945.7598
53.67	0.014	228.7	0.007	0.001	80	935.9173
56.67	0.004	332.5	0.003	-0.005	81	926.0748
59.67	0.005	249	0.002	0	77	916.2323
62.67	0.009	351.7	0	0	79	906.3898
65.67	0.013	31.3	-0.004	0.004	81	896.5472
68.67	0.018	47.9	0.001	0.003	80	886.7047
71.67	0.012	55.6	-0.003	0	78	876.8622
74.67	0.013	31.9	-0.004	-0.005	76	867.0197
77.67	0.011	16.5	-0.001	0.002	75	857.1772
80.67	0.011	41.1	-0.001	0	79	847.3346
83.67	0.017	3.8	0.002	0.001	53	837.4921

Table A3 - November 30, 2007 ADCP Profile (average of 600 ensembles). Low percent good values result from windy conditions. File=LMXR009R.000

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev(ft)
5.62	0.074	27.8	-0.008	0.006	19	1092.662
8.62	0.061	41	0.004	0.008	31	1082.819
11.62	0.07	36.4	-0.014	0.001	35	1072.977
14.62	0.056	42.4	-0.001	0	36	1063.134
17.62	0.03	55.7	-0.009	0	32	1053.292
20.62	0.042	21.5	0.002	0.005	37	1043.449
23.62	0.028	28.7	-0.004	0.002	35	1033.607
26.62	0.034	23	-0.003	-0.002	40	1023.764
29.62	0.023	7.6	-0.014	0.002	40	1013.922
32.62	0.031	55.5	-0.006	-0.005	39	1004.079
35.62	0.038	74.8	-0.004	-0.002	40	994.2365
38.62	0.009	102.8	-0.009	-0.007	38	984.394
41.62	0.03	191.7	-0.001	0	39	974.5514
44.62	0.03	225	-0.009	-0.009	36	964.7089
47.62	0.022	172.4	-0.005	-0.004	33	954.8664
50.62	0.016	148.9	-0.008	-0.008	35	945.0239
53.62	0.01	3.8	-0.01	0	35	935.1814
56.62	0.008	333	-0.017	-0.003	29	925.3388
59.62	0.022	294	0.001	0.004	30	915.4963
62.62	0.001	86.6	-0.001	0.005	33	905.6538
65.62	0.008	335.9	-0.008	-0.003	31	895.8113
68.62	0.013	2.6	-0.014	0.003	30	885.9688
71.62	0.012	296.6	-0.009	-0.005	29	876.1262
74.62	0.026	17.7	-0.009	0.01	22	866.2837
77.62	0.04	326.2	-0.005	0.015	19	856.4412

Table A4 – January 3, 2008 ADCP Profile (average of 400 ensembles).
File=LMXR011R.000

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev. (ft)
5.6	0.07	79.4	-0.001	0.005	81	1096.527
8.6	0.061	75.7	0.003	-0.001	82	1086.685
11.6	0.063	82.2	0.002	-0.004	86	1076.842
14.6	0.062	82.3	0.002	0.004	82	1067
17.6	0.054	71.1	0.004	-0.003	84	1057.157
20.6	0.054	77.3	0.005	-0.003	83	1047.315
23.6	0.064	80.4	0	-0.001	84	1037.472
26.6	0.066	79.6	0.002	0.003	78	1027.63
29.6	0.067	72	0.004	-0.003	81	1017.787
32.6	0.07	79.6	0	0.006	88	1007.945
35.6	0.06	84.2	0	0.002	82	998.1021
38.6	0.054	86.1	0	0.002	84	988.2596
41.6	0.054	69.5	0.001	-0.004	80	978.4171
44.6	0.053	86.3	0.001	-0.004	86	968.5745
47.6	0.05	84.6	0	-0.001	81	958.732
50.6	0.05	80.7	0	0.001	82	948.8895
53.6	0.031	76.7	0	-0.001	84	939.047
56.6	0.033	93.7	0.001	-0.002	81	929.2045
59.6	0.019	147.8	0.001	0.012	77	919.3619
62.6	0.028	207.2	-0.001	0.002	73	909.5194
65.6	0.009	244.3	0	-0.005	73	899.6769
68.6	0.022	174.6	0.002	-0.001	74	889.8344
71.6	0.025	176.6	0.002	-0.004	76	879.9919
74.6	0.022	175.7	-0.001	-0.006	78	870.1493
77.6	0.018	180.2	0	-0.001	72	860.3068
80.6	0.006	167	0.002	0.004	73	850.4643
83.6	0.01	144.8	0	0.002	67	840.6218
86.6	0.01	139.4	0.001	0	67	830.7793
89.6	0.013	196.5	-0.001	-0.007	63	820.9367
92.6	0.014	200	0.001	0.003	63	811.0942
95.6	0.037	190.1	0.002	0.002	45	801.2517
98.6	0.019	225.7	0	-0.002	50	791.4092
101.6	0.022	235.9	0.003	0	41	781.5667

Table A5 – March 10, 2008 ADCP Profile (average of 850 ensembles).
File=LMXR020R.000

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev. (ft)
5.6	0.02	33.2	-0.003	-0.001	80	1099.427
8.6	0.02	150.4	0	0.001	82	1089.585
11.6	0.045	154.3	-0.002	0.002	86	1079.742
14.6	0.047	162	-0.001	0	80	1069.9
17.6	0.043	162.7	0	-0.002	84	1060.057
20.6	0.026	163	0.001	0.001	81	1050.215
23.6	0.023	176.4	0	0.001	81	1040.372
26.6	0.017	206.9	0	0.001	82	1030.53
29.6	0.022	217.3	-0.001	0	81	1020.687
32.6	0.021	235.3	-0.002	0	83	1010.845
35.6	0.022	222.4	0.001	-0.003	81	1001.002
38.6	0.022	239.7	-0.001	-0.005	82	991.1596
41.6	0.017	209.1	-0.002	-0.001	78	981.3171
44.6	0.015	199.6	-0.004	0.002	78	971.4745
47.6	0.014	225.6	-0.003	0	82	961.632
50.6	0.014	220.2	-0.003	0.003	79	951.7895
53.6	0.015	189.2	-0.003	0.001	76	941.947
56.6	0.009	189.6	0	-0.002	76	932.1045
59.6	0.01	316.3	-0.003	0	78	922.2619
62.6	0.013	286.4	-0.001	0	77	912.4194
65.6	0.013	268.1	-0.001	0.002	72	902.5769
68.6	0.01	266.8	-0.004	0.002	74	892.7344
71.6	0.005	297	-0.002	0.002	70	882.8919
74.6	0.008	186.8	-0.002	0.003	69	873.0493
77.6	0.008	216.2	-0.002	0	68	863.2068
80.6	0.008	302.1	-0.002	-0.003	69	853.3643
83.6	0.015	246.7	-0.003	0.001	60	843.5218
86.6	0.007	263	-0.003	0.004	45	833.6793

Table A6 – May 28, 2008 ADCP Profile (average of 830 ensembles).
File=LMXR030R.000

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev. (ft)
5.63	0.028	340.5	-0.008	0.001	71	1089.029
8.63	0.023	359.8	-0.011	0.001	75	1079.186
11.63	0.044	16.7	-0.008	-0.007	73	1069.344
14.63	0.058	49.2	-0.008	-0.003	75	1059.501
17.63	0.052	109	-0.007	-0.002	74	1049.659
20.63	0.035	201.3	-0.007	0.002	74	1039.816
23.63	0.016	310.9	-0.007	0.001	74	1029.974
26.63	0.033	21.6	-0.005	0	69	1020.131
29.63	0.039	17	-0.006	0.001	73	1010.289
32.63	0.019	34.6	-0.006	-0.002	76	1000.446
35.63	0.019	58.5	-0.009	-0.002	73	990.6037
38.63	0.007	38.2	-0.008	0	74	980.7612
41.63	0.009	317	-0.01	-0.001	72	970.9186
44.63	0.01	243	-0.008	-0.002	75	961.0761
47.63	0.011	183.5	-0.007	-0.003	73	951.2336
50.63	0.01	214.8	-0.004	0.001	74	941.3911
53.63	0.002	16.4	-0.007	0	71	931.5486
56.63	0.006	213.5	-0.007	-0.006	71	921.706
59.63	0.014	224.9	-0.003	-0.003	74	911.8635
62.63	0.019	223.2	-0.005	0.004	72	902.021
65.63	0.017	232.8	-0.002	-0.002	70	892.1785
68.63	0.015	240.3	-0.004	-0.002	71	882.336
71.63	0.016	299.2	-0.009	-0.001	68	872.4934
74.63	0.012	274.5	-0.007	-0.005	63	862.6509
77.63	0.011	263.6	-0.005	0	57	852.8084
80.63	0.019	312.8	-0.005	-0.004	51	842.9659
83.63	0.017	281.8	0.003	0.001	45	833.1234

Table A7 – July 29, 2008 ADCP Profile (average of 1860 ensembles).
File=LMXR036R.000

Low percent good values result from windy conditions.

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev. (ft)
5.66	0.072	293.9	0.002	-0.014	9	1086.13
8.66	0.077	308.7	-0.002	0.005	23	1076.288
11.66	0.081	293.4	0.001	-0.002	32	1066.445
14.66	0.052	283.9	0.002	0.001	44	1056.603
17.66	0.007	256.9	0.005	-0.002	43	1046.76
20.66	0.016	340.8	0.004	0.004	46	1036.918
23.66	0.014	277.6	0.006	0.003	41	1027.075
26.66	0.021	207.4	0.006	0.002	44	1017.233
29.66	0.023	238.2	0	0.002	45	1007.39
32.66	0.02	242.4	0.003	0	44	997.5478
35.66	0.015	261.2	-0.002	0.003	42	987.7052
38.66	0.018	298.5	0.003	0.004	44	977.8627
41.66	0.022	346.8	0.004	0.003	43	968.0202
44.66	0.008	60.1	0.004	-0.002	40	958.1777
47.66	0.021	5.7	0.004	-0.001	41	948.3352
50.66	0.013	19.1	0.003	0.001	39	938.4927
53.66	0.019	25.7	0.002	0.003	38	928.6501
56.66	0.012	334.9	0.001	0.004	37	918.8076
59.66	0.018	336.1	0.002	0.001	36	908.9651
62.66	0.009	329.6	0.002	-0.001	36	899.1226
65.66	0.001	94.9	-0.001	0.001	34	889.2801
68.66	0.004	284.8	-0.003	-0.001	33	879.4375
71.66	0.012	346.1	-0.002	0.004	29	869.595
74.66	0.016	347.2	-0.001	0.002	25	859.7525

Table A8 – September 18, 2008 ADCP Profile (average of 1100 ensembles).
File=LMXR040R.000

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev. (ft)
5.65	0.035	184.7	-0.001	0	100	1086.863
8.65	0.029	175.9	-0.001	0.001	100	1077.021
11.65	0.013	133.8	0	0.005	100	1067.178
14.65	0.012	136	-0.001	-0.003	100	1057.336
17.65	0.018	145.9	-0.001	0.003	100	1047.493
20.65	0.009	144.5	0	-0.006	100	1037.651
23.65	0.007	133.2	0.003	-0.007	100	1027.808
26.65	0.003	231.4	0.001	-0.009	100	1017.966
29.65	0.015	287.3	0	-0.005	100	1008.123
32.65	0.015	281.1	0.001	-0.003	100	998.2806
35.65	0.017	246.9	0.001	0.006	100	988.4381
38.65	0.023	192.2	0	-0.002	100	978.5955
41.65	0.02	191.2	-0.002	-0.002	100	968.753
44.65	0.012	200.1	-0.002	0	100	958.9105
47.65	0.005	178.6	-0.001	0	100	949.068
50.65	0.005	254.8	-0.001	0.002	100	939.2255
53.65	0.004	204.2	0	0.002	100	929.3829
56.65	0.004	260.4	0	0.001	100	919.5404
59.65	0.002	220.7	-0.001	-0.001	100	909.6979
62.65	0.005	278.7	-0.002	-0.002	100	899.8554
65.65	0.007	250.9	-0.002	-0.004	99	890.0129
68.65	0.003	170	-0.003	0	99	880.1703
71.65	0.007	186.8	-0.003	-0.002	98	870.3278
74.65	0.009	187.8	-0.002	0.002	98	860.4853
77.65	0.002	206.8	-0.002	-0.002	97	850.6428
80.65	0.004	185.3	-0.002	0.001	96	840.8003
83.65	0.004	190.3	-0.003	0.001	97	830.9577
86.65	0.01	238.8	-0.003	-0.001	96	821.1152
89.65	0.008	160.9	-0.002	0.003	96	811.2727
92.65	0.011	223.2	0	-0.006	77	801.4302

Table A9 – December 4, 2008 ADCP Profile (average of 1120 ensembles).
File=LMXR048R.000

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev. (ft)
5.62	0.066	167.7	-0.006	-0.007	99	1089.062
8.62	0.056	173.5	-0.001	-0.001	99	1079.219
11.62	0.054	174.2	0.002	0.001	100	1069.377
14.62	0.052	173.6	0.002	0.005	100	1059.534
17.62	0.046	177.4	0.005	0.001	100	1049.692
20.62	0.045	172.4	0.004	0.001	100	1039.849
23.62	0.047	179.8	0.003	-0.004	100	1030.007
26.62	0.037	181.1	0.003	-0.002	100	1020.164
29.62	0.033	196.1	0.001	-0.001	100	1010.322
32.62	0.033	186.4	-0.002	0.001	100	1000.479
35.62	0.037	181.4	-0.001	0.001	100	990.6365
38.62	0.032	213	-0.001	0.001	100	980.794
41.62	0.017	216.5	-0.001	0.003	100	970.9514
44.62	0.01	206.9	-0.002	0	100	961.1089
47.62	0.002	34.7	-0.003	0	100	951.2664
50.62	0.014	18.1	-0.002	0.003	99	941.4239
53.62	0.018	19.7	-0.002	0.001	99	931.5814
56.62	0.003	27.3	-0.001	-0.002	99	921.7388
59.62	0.009	209	-0.003	-0.004	98	911.8963
62.62	0.016	180.1	-0.002	0.001	95	902.0538
65.62	0.004	98.8	-0.003	0.006	91	892.2113
68.62	0	16.8	-0.006	0.001	82	882.3688
71.62	0.007	93.4	-0.003	0.006	71	872.5262
74.62	0.003	83	-0.001	0.008	61	862.6837
77.62	0.006	148.1	-0.003	0.009	50	852.8412
80.62	0.009	114	0	0.005	45	842.9987

Table A10 – March 19, 2009 ADCP Profile (average of 1130 ensembles).
File=LMXR053R.000

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev. (ft)
5.62	0.022	263.5	0	-0.002	100	1091.262
8.62	0.023	253	-0.001	-0.002	100	1081.419
11.62	0.017	203	-0.001	0.001	100	1071.577
14.62	0.015	209.7	-0.002	0.003	100	1061.734
17.62	0.021	209.4	-0.001	-0.002	100	1051.892
20.62	0.021	236.8	0.001	-0.001	100	1042.049
23.62	0.015	240.7	0.001	0.004	100	1032.207
26.62	0.015	208.5	-0.001	0.006	100	1022.364
29.62	0.013	229.2	-0.001	0.003	100	1012.522
32.62	0.018	229.2	-0.003	-0.003	100	1002.679
35.62	0.014	215.9	-0.003	0.001	100	992.8365
38.62	0.012	179.9	-0.002	0	100	982.994
41.62	0.013	236.5	-0.002	0.001	99	973.1514
44.62	0.013	223.8	-0.003	0.004	99	963.3089
47.62	0.02	178.6	-0.003	0.002	97	953.4664
50.62	0.018	192.9	-0.003	0.005	96	943.6239
53.62	0.015	181.3	-0.004	0.005	91	933.7814
56.62	0	49.3	-0.004	0.003	90	923.9388
59.62	0.007	26.4	-0.003	0.004	83	914.0963
62.62	0.008	43	-0.003	0.004	80	904.2538
65.62	0.011	6.3	-0.005	0.009	77	894.4113
68.62	0.021	12.5	-0.003	0.009	66	884.5688
71.62	0.026	6.1	0.001	0.012	58	874.7262

Table A11 – June 4, 2009 ADCP Profile (average of 1000 ensembles).
File=LMXR058R.000

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev. (ft)
5.65	0.024	287.5	-0.004	-0.002	76	1078.163
8.65	0.017	14.2	-0.001	0	80	1068.321
11.65	0.024	100.3	0	-0.003	83	1058.478
14.65	0.017	80.8	0.002	0	81	1048.636
17.65	0.016	70.9	0.001	0.001	83	1038.793
20.65	0.008	300.3	0	-0.002	83	1028.951
23.65	0.012	246.9	0.002	0.001	81	1019.108
26.65	0.008	252	0	0.004	82	1009.266
29.65	0.009	246.1	0.001	0.003	83	999.4231
32.65	0.02	229.3	0.001	0.001	81	989.5806
35.65	0.025	224.6	0.001	0.001	81	979.7381
38.65	0.03	222.8	-0.001	-0.001	81	969.8955
41.65	0.031	204.4	0.001	-0.001	79	960.053
44.65	0.023	207	0	-0.001	82	950.2105
47.65	0.028	211.2	0.003	0.002	81	940.368
50.65	0.022	207.6	0	0.001	82	930.5255
53.65	0.009	230.3	0	0	83	920.6829
56.65	0.011	206	-0.001	-0.001	81	910.8404
59.65	0.006	154.3	0	0.002	82	900.9979
62.65	0.002	41.6	0	0.001	80	891.1554
65.65	0.009	352	0	0.002	80	881.3129
68.65	0.014	69.8	-0.001	0.003	80	871.4703
71.65	0.009	58.3	-0.001	0.002	81	861.6278
74.65	0.018	33.4	0.001	0.002	80	851.7853
77.65	0.013	42.8	0.001	0.001	83	841.9428
80.65	0.017	44.3	0.001	0.002	80	832.1003
83.65	0.017	45	-0.002	-0.001	79	822.2577
86.65	0.024	81.4	0.001	0	61	812.4152

Table A12 – August 26, 2009 ADCP Profile (average of 1900 ensembles).
File=LMXR066R.000

Depth(m)	Vmag (m/sec)	Vdir (deg)	Vup (m/sec)	Verror (m/sec)	%good	Elev. (ft)
5.66	0.052	5.8	0.001	-0.002	73	1075.43
8.66	0.058	26	0	-0.002	78	1065.588
11.66	0.029	60.6	0	0	73	1055.745
14.66	0.031	207.4	0	-0.002	84	1045.903
17.66	0.033	210.2	0.001	0	78	1036.06
20.66	0.011	166.5	0.002	0.001	79	1026.218
23.66	0.011	42	0	0	79	1016.375
26.66	0.014	1.7	0.001	0.002	80	1006.533
29.66	0.018	328.4	0	0.001	78	996.6903
32.66	0.018	264.2	0	0.001	80	986.8478
35.66	0.021	256	0.001	-0.001	81	977.0052
38.66	0.013	300.8	0	0	80	967.1627
41.66	0.009	341.6	0.001	-0.001	80	957.3202
44.66	0.009	24.1	0	-0.001	80	947.4777
47.66	0.004	356.7	0	-0.001	80	937.6352
50.66	0.001	97.9	-0.001	0	78	927.7927
53.66	0.005	115.9	0	0	80	917.9501
56.66	0.003	299	-0.001	0.002	80	908.1076
59.66	0.005	319.4	-0.001	0	79	898.2651
62.66	0.006	279	-0.001	0.002	79	888.4226
65.66	0.007	225.5	-0.002	0	79	878.5801
68.66	0.011	210.2	-0.001	0.001	80	868.7375
71.66	0.007	198.3	0	0	78	858.895
74.66	0.009	206.2	0	-0.001	78	849.0525
77.66	0.006	203.9	0	0	75	839.21
80.66	0.009	170.9	0	0.001	67	829.3675
83.66	0.005	167.2	-0.001	-0.002	60	819.5249
86.66	0.002	315.6	0.001	-0.003	50	809.6824

List of ADCP Configuration Commands

[RDI WinRiver Configuration File]

```
Version=10.06.00
 [Offsets]
ADCP Transducer Depth [m]=0.3048
Magnetic Variation [deg]=12.5
Heading Offset [deg]=0
One Cycle K=0
One Cycle Offset=0
Two Cycle K=0
Two Cycle Offset=0
[Processing]
Speed of Sound Correction=0
Salinity [ppt]=0
Fixed Speed of Sound [m/s]=1500
Mark below bottom Bad=YES
Screen Depth=NO
Backscatter Type=0
Intensity Scale [dB/cts]=0.43
Absorption [dB/m]=0.139
Projection Angle [deg]=0
 [GPS]
GPS Time Delay [s]=0
[Recording]
Filename Prefix=LMXR
Output Directory=C:\ADCP\SNWS\
GPS Recording=YES
DS Recording=NO
Maximum File Size [MB]=0
Comment #1=SNWS DEEP WATER INTAKE PROFILES 3M CELLS
EXTENDED RANGE
Comment #2=LAKE MEAD STATION CR348.4NW0.8
Next Transect Number=0
Add Date Time=NO
```

[ADCP Commands]

```
WF75              WD111100000
WM1               EX11111
BM5               EZ1111111
WV80              ED3
WN50              WB1
WS300             CF11111
WP1               BX2743
BP1               TP000050
```

Results of PlanADCP model on ADCP Performance

```
CR1
CF11111
WM1
BM5
BP500
BX4000
EA0
EB1250
ED3
ES0
EX11111
EZ1111111
WA50
WB1 – Narrow bandwidth processing option
WD111100000
WF176
WN50
WP500
BP500
WS300
WV80
TE01:00:00.00
TP00:03.60
CK
CS
;Instrument        = Workhorse Monitor
;Frequency         = 307200
;Water Profile     = YES
;Bottom Track      = YES
;High Res. Modes   = NO
;High Rate Pinging  = NO
;Shallow Bottom Mode= NO
;Wave Gauge        = NO
;Lowered ADCP      = NO
;Beam angle        = 20
;Temperature       = 15.00
;Deployment hours   = 2400.00
;Battery packs     = 0
;Automatic TP      = YES
;BT range [m]      = 200.00
;Memory size [MB]   = 256
;Saved Screen      = 3
;Consequences generated by PlanADCP version 2.04:
;First cell range   = 5.35 m
;Last cell range    = 152.35 m
;Max range         = 382.14 m
;Standard deviation = 0.37 cm/s – this is the expected velocity magnitude uncertainty
for an ensemble of 500 water pings.
;Ensemble size     = 1241 bytes
;Storage required   = 2.84 MB (2978400 bytes)
;Power usage       = 4689.48 Wh
```