ACOUSTIC DOPPLER VELOCITY MEASUREMENTS IN BOULDER BASIN, LAKE MEAD, AUGUST 1999

by

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Peer Reviewer Jim LaBounty Document Author(s)/Preparer(s) Tracy Vermeyen

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Introduction

The Bureau of Reclamation has conducted a series of limnological investigations of the Boulder Basin of Lake Mead beginning in July 1990 and has been continuous thereafter (Labounty and Horn, 1997). The purpose of this study is to: 1) collect trend data on the influence of the wastewater and other drainage from the Las Vegas Basin via Las Vegas Wash into Las Vegas Bay; 2) investigate the status of the limnological conditions of Boulder Basin as a source of supply for drinking water; 3) perform research into new technology for evaluating limnological features, in particular those related to water quality conditions of reservoirs, and 4) contribute to understanding the ecology of Lake Mead as it relates to the operational scheme of the Colorado River system. Funding for these activities was provided from both the Lower Colorado Region's resource management budget and Reclamation's research budget.

Lake Mead is a large mainstem Colorado River reservoir in the Mohave Desert, Arizona-Nevada (Figure 1). Its lower end is 15 km east of Las Vegas, Nevada. Lake Mead, formed in 1935 following construction of Hoover Dam is the largest reservoir in the United States by volume (36.7×10^9 m^3), and is second only to Lake Powell in terms of surface area (660 km^2). Lake Mead has four large sub-basins: Boulder, Virgin, Temple, and Gregg. The lake also includes four narrow canyons: Black, Boulder, Virgin, and Iceberg (Figure 1).

Retention time in the reservoir is on average 3.9 years, depending on release and inflow patterns. The Colorado River contributes about 98 percent of the annual inflow to Lake Mead; the remaining three inflows, the Virgin and Muddy Rivers, and Las Vegas Wash, provide the remainder. Annual inflow via Las Vegas Wash is currently about 1.9×10^8 m^3, and provides the second highest inflow volume to Lake Mead. Discharge from Hoover Dam is hypolimnetic and occurs 83 m below the maximum operating level of 364 m above msl. Hoover Dam's annual discharge is approximately 9×10^9 m^3 or 7.3×10^6 acre-ft. Annual withdrawal through the Southern Nevada Water System Intake in Boulder Basin is presently about 0.55×10^9 m^3 or 446,000 acre-ft (Roefer et al. 1996).

As with other reservoirs, dam operations exert a great influence on Lake Mead's water quality and ecology (Thornton 1990). Unfortunately, the hydrodynamics of such large reservoirs are complex and not well understood. Each basin within Lake Mead is ecologically unique, and therefore responds differently to the inflow-outflow regime. Furthermore, different sources of water entering Lake Mead, as in other reservoirs, often retain their identity and influence for substantial distances into the reservoir and do not necessarily mix completely with the rest of the water column (Ford 1990). This can lead to significant underestimates of water retention time, transport rates, and fate of materials transported into the reservoir.

Boulder Basin is the most downstream basin and collects the combined flows from the reservoir's two main arms (Figure 1). Additionally, it receives all drainage from the Las Vegas Valley via Las Vegas Wash into Las Vegas Bay. This drainage includes both non-point surface and groundwater discharges, as well as treated effluent from municipal wastewater treatment facilities.

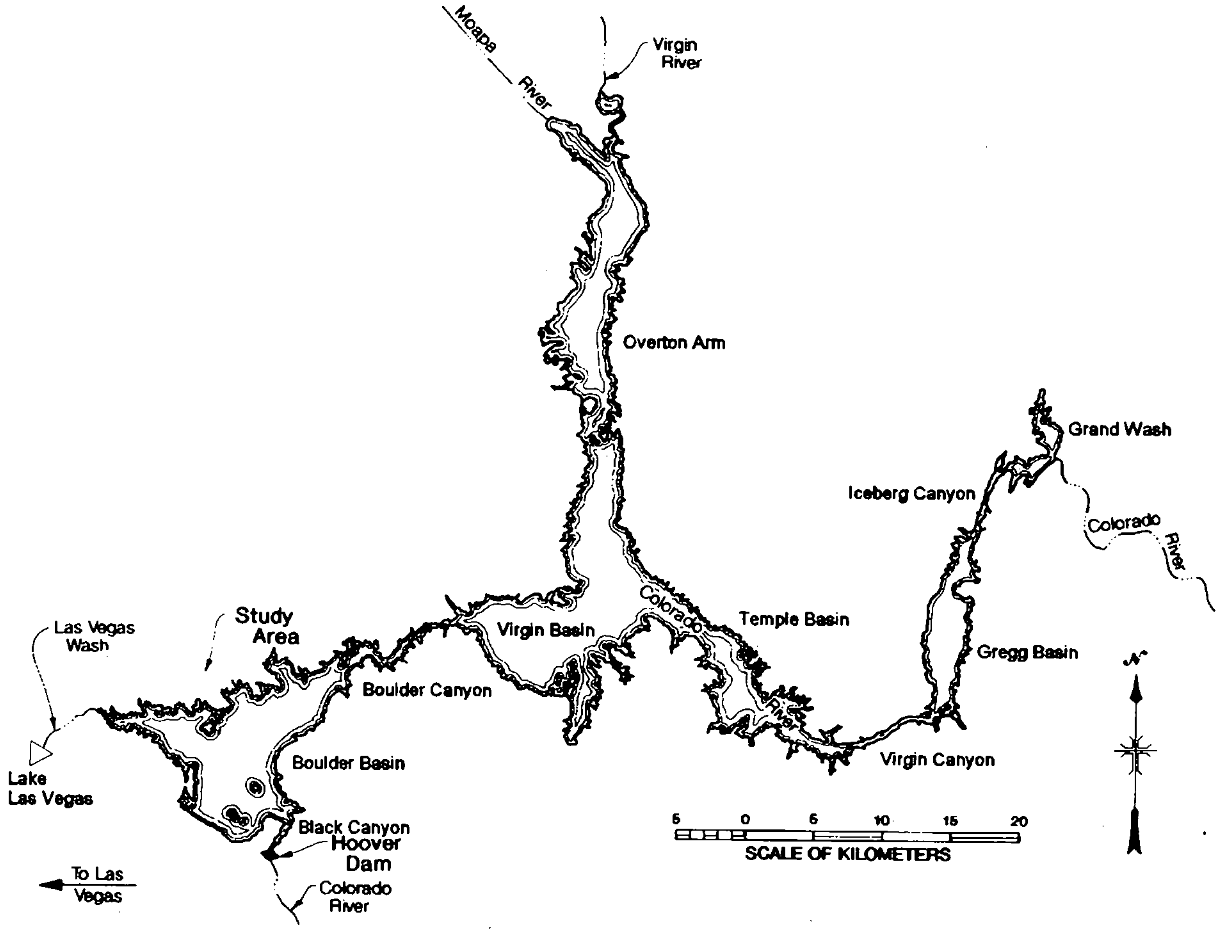


Figure 1. Map of Lake Mead.

Boulder Basin is 15 km wide from Boulder Canyon to Hoover Dam (Black Canyon), and the distance from the confluence of Las Vegas Wash to Hoover Dam is approximately 16 km. The historical Colorado River channel lies along the eastern side of the basin.

The morphology and hydrodynamics of Lake Mead are such that the nutrient loading, as a result of discharges through Las Vegas Wash, is confined to Boulder Basin (Paulson and Baker 1981, Prentki and Paulson 1983). The seasonal hydrodynamics of the interflow created by Las Vegas Wash inflows are described in detail by Labounty and Horn (1997). Boulder Basin serves as the primary source of drinking water for the Las Vegas Valley which includes nearly 1.5 million people. Water from Lake Mead serves nearly 25 million downstream users. In addition, the reservoir is the major outdoor recreation feature of the Lower Colorado River visited by millions of people each year. Included in the Bureau of Reclamation's mission is the management of the water resources of this and other water sources of the western United States in an environmentally and economically sound manner. In order to carry out this defined mission, it is imperative that we understand the ecological features of Lake Mead.

Purpose

As per discussions with Jim LaBounty, Chris Holdren (D-8220), and Gordon Mueller (USGS/MESC) acoustic Doppler current profiler (ADCP) measurements are needed to describe the hydrodynamic characteristics of the Las Vegas Wash interflow into Lake Mead. The scope of work for these acoustic measurements was as follows:

1) Locate the interflow at various stations (LV01-LV14) and to measure the average velocity in the plume. This information will be useful in determining the travel time of interflow from Las Vegas Wash to Saddle Island. Stationary velocity profiles were collected during limnological sampling to establish interflow velocities at these stations.

2) At several stations, ADCP transects were collected to measure the horizontal extent (spreading) of the interflow. This information was used to describe the three dimensional characteristics of the interflow. These transects were also used to document cross sectional area for each transect.

3) Coordinate ADCP measurements with Mueller's hydroacoustic surveys so that the combined data sets can be combined into a GIS database. These data will be used to create a multi-layer GIS map which describes fish location and density, interflow extents, bathymetry, and selected limnological parameter distribution. GPS measurements collected with the ADCP transects will be used to determine the position of each profile collected. Mueller will also use GPS to fix the position of the hydroacoustic transects.

4) An acoustic Doppler velocimeter (ADV) was used to make detailed point velocity measurements inside the interflow. The ADV was lowered into the interflow using a sounding weight and winch. This instrument wasill be used to collect interflow velocity profiles at several of the limnological sampling sites.

5) Develop a data set for Terry Fulp (BCOO-4626) to use for developing a water quality model of Boulder Basin. Fulp will attempt to develop a predictive model of water quality at Saddle Island under various inflow regimes (e.g. stratified and well mixed).

Sampling Methods

Acoustic Doppler velocity measurements were collected done during a normal site visit by the limnologists. Velocity data were collected August 2-3, 1999. The velocity profiling program was designed to examine the characteristics of the Las Vegas Wash interflow (plume) entering Lake Mead as a distinct flow. Sampling locations in Boulder Basin are shown in Figure 2. Detailed sampling station descriptions and locations, as well as analytical methods used by the Lower Colorado Regional Laboratory for sample analysis, were provided in a previous report (Holdren et al., 1998).

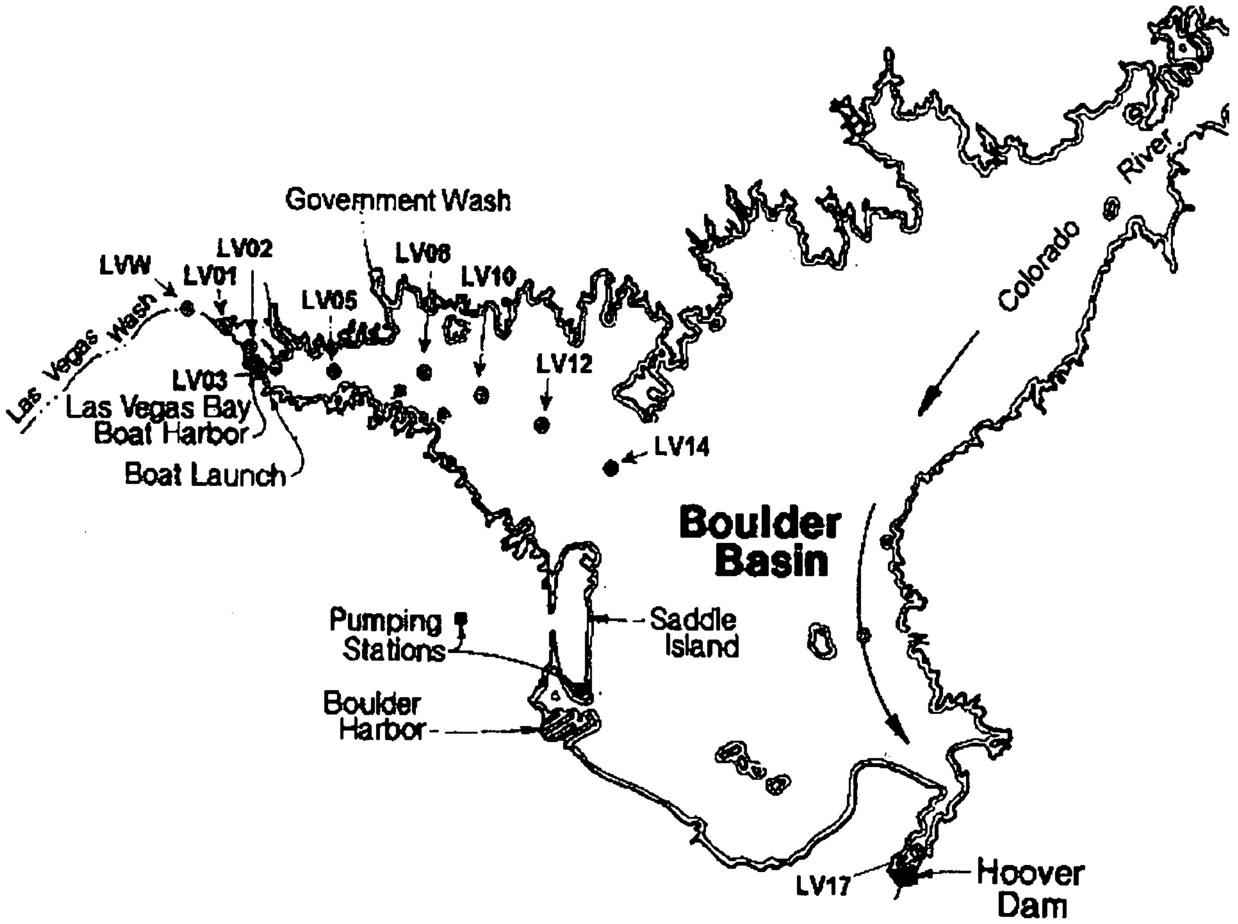


Figure 2. Boulder Basin sampling locations visited during the August 2-3, 1999 data collection.

The limnologists use a Hydrolab Surveyor IV to measure temperature, dissolved oxygen concentration, dissolved oxygen saturation, pH, conductivity and turbidity in profile at eachsampling location. Additional samples were collected for nutrients, Perchlorate, and biological characteristics. Nutrients (inorganic phosphate [PO4-P], ammonia [NH3-N], and nitrate [NO3-N]) were collected from the surface and from depths of 1 m, 3 m, and the plume depth. Surface samples were collected as grabs and a Van Dorn sampler was used to collect samples from the other depths. A small conductivity meter inserted in the Van Dorn sampler was used to verify that plume samples were collected from the correct depth. Secchi depth, weather conditions and water color were also recorded at each station.

Velocity measurements were collected using an RD Instruments ADCP and a Sontek ADV. Velocity profile data were collected using both instruments at the same sites visited by the limnologists. Duplicate measurements were required because the ADCP is limited in its ability to measure low velocities, whereas the ADV does not have this limitation.

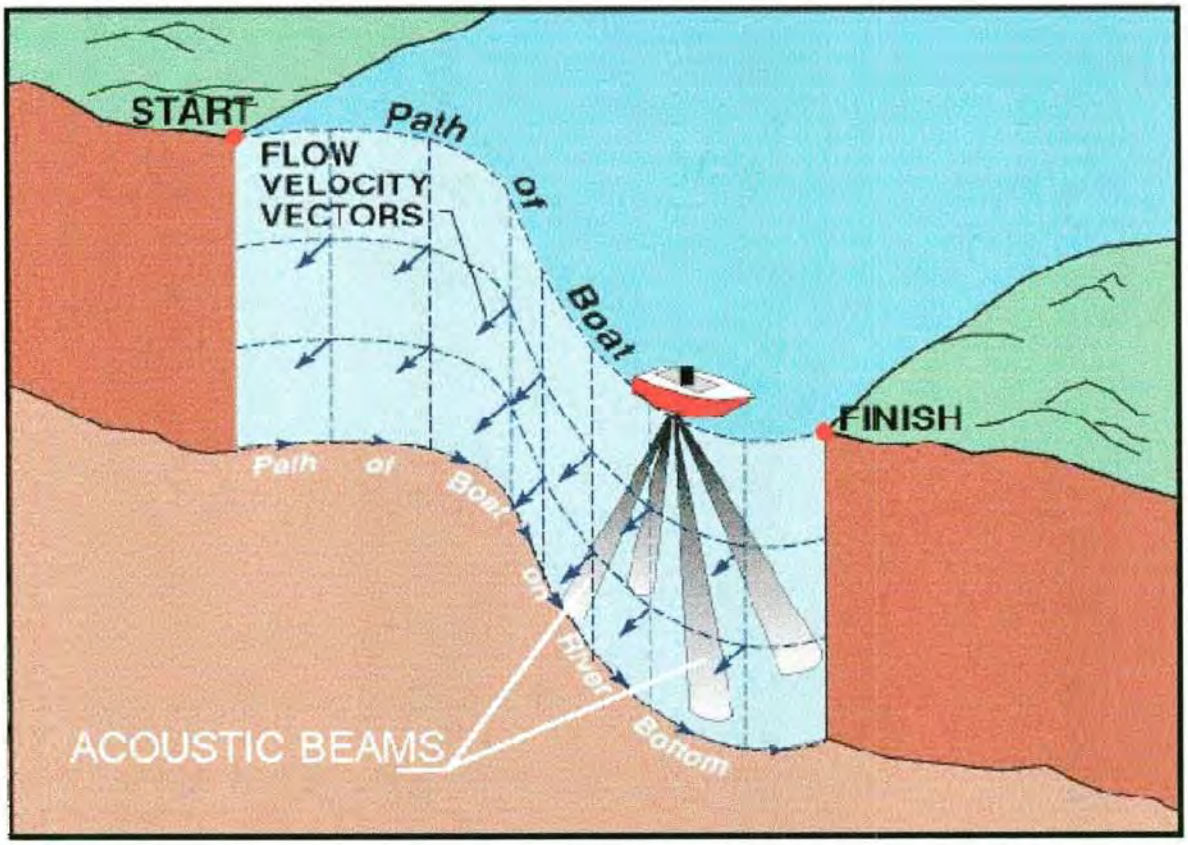


Figure 3. Schematic of the acoustic beam configuration for a boat-mounted ADCP transect.

ADCP Measurements

Data were collected using an RD Instruments broadband ADCP, operated from both a stationary and 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., organic or inorganic particles). 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 100 centimeters each, yielding a velocity profile from near the surface to near the bed. Velocities cannot be measured near the surface because the transducer must be submerged and there is some time delay between the send and receive modes of operation. 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 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 is used to configure the ADCP and collect and store the data. A portable global positioning system (GPS) is also connected to the laptop computer so that continuous GPS data are recorded simultaneously with the velocity data. The GPS is also used to record waypoints at the beginning and end of each transect.

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

Acoustic Doppler Velocimeter (ADV) Measurements

The ADV uses Doppler techniques to simultaneously measure three velocity components (x, y, and z) of flowing water using a single sampling volume. The orientation of the three velocity components are defined as positive with V_x in the upstream direction, positive V_y is toward the right bank, and positive V_z is upward. This convention follows a right-handed coordinate system. The ADV sampling volume is located 5 cm (2 in.) below the probe head and is cylindrical in shape (the probe volume is less than 0.25 cm^3). Consequently, the sounding weight had minimal impact on the flow field surrounding the measurement volume.

The profiling method involved lowering a 23 kg lead sounding weight, which contained the ADV probe (figure 4), to below the Las Vegas Wash interflow. Once the weight was in position, a 30-second sample at a frequency of 25 Hz was collected for a total of 750 velocity measurements. Next, the sounding weight was winched up a distance of 1 meter and another set of velocity data were collected. The depth of the ADV probe was measured using a flexible tape that was attached to the sounding weight.

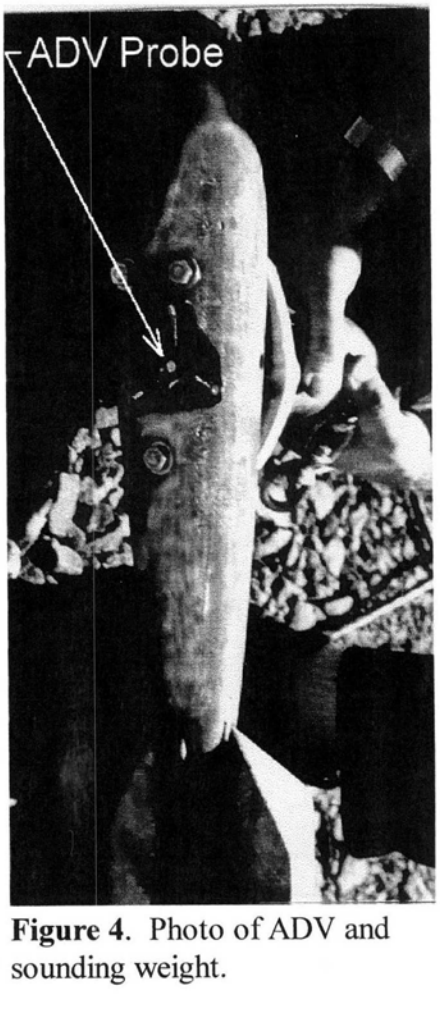


Figure 4. Photo of ADV and sounding weight.

Typically, when the sounding weight system is used in flowing water the fins orient the ADV probe's x-axis parallel to the flow direction. For this application, the flow was not sufficient to keep the probe oriented into the flow. As a result, it was not possible to determine the direction of the water currents using the ADV. This probe was not equipped with a compass. As a result, only the speed of the horizontal currents could be determined. In locations where the ADCP could measure velocity accurately, this limitation was overcome by using the ADCP profiles to determine the direction of the water currents.

ADV data were collected and viewed in real-time via a laptop computer system. Notes were made when boat wakes and wind waves caused a deterioration of data quality.

Operations

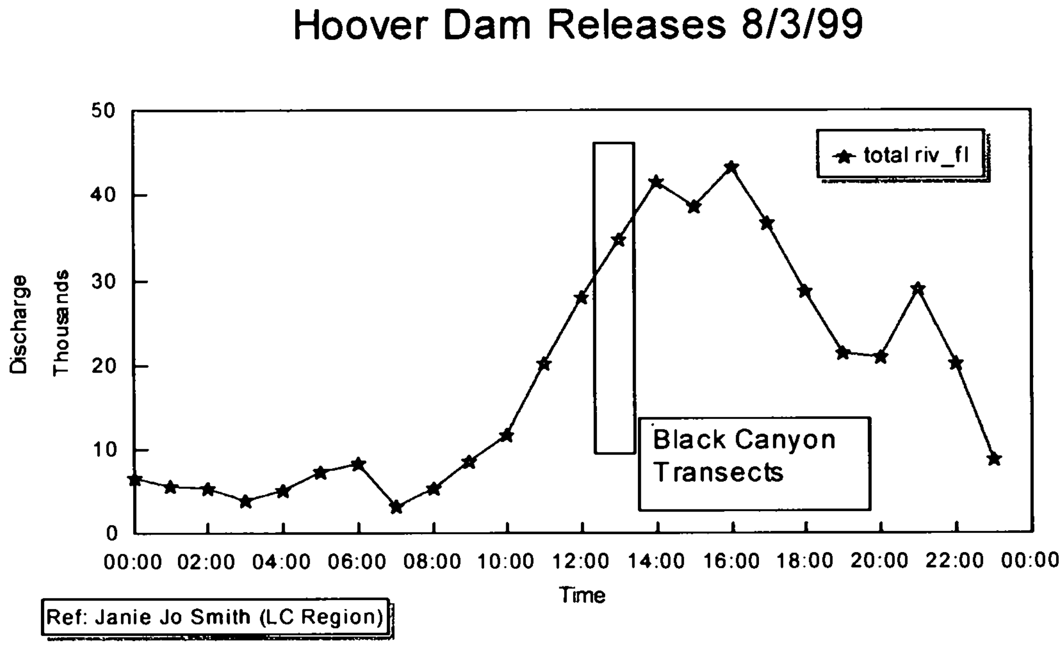
Lake Mead's water surface elevation for the two days of data collection was 368.0 m (1207.4 ft). ADCP transects were collected across the entrance to Black Canyon from 12:30 and 1:00 p.m. As shown in figure 5, Hoover Dam releases for this time period were between 790 and 990 m^3/sec (28,000 and 35,000 ft^3/sec).

Daily mean flows in Las Vegas Wash at USGS gaging station 9419790 were 6.3 m^3/sec (222 ft^3/sec) on Aug. 2 and 6.2 m^3/sec (218 ft^3/sec) on August 3, 1999 (see figure 6). The average daily releases from Hoover Dam were 405 m^3/sec (14,300 ft^3/sec) on August 2 and 532 m^3/sec (18,800 ft^3/sec) on August 3, 1999 (data provided by Janie Jo Smith, BCOO-4625).

The flows through the SNWS pumping plant at Saddle Island were about 12 m^3/sec (420 ft^3/sec) on August 3, 1999 (personal communication with Peggy Roefer, SNWA). A total of 8 pumps were running, which is about half of the plant's total capacity.

Another important hydrologic event which is relevant to this study was a flash flood that occurred prior to this field work. On July 8, 1999, the Las Vegas Valley experienced a heavy rainfall event that resulted in flash flooding in Las Vegas Wash (Roefer 1999). The Clark County Regional Flood Control District reported this flood to be a 125-year recurrence interval flood. The maximum flow rate in the Wash was estimated to be 450 m^3/sec (16,000 ft^3/sec). This flood carried a large amount of debris and sediment into Las Vegas Bay.

It is important to note that the hydrodynamic characteristics of the Las Vegas Wash interflow moving into Las Vegas Bay are primarily a function of the Las Vegas Wash inflows (LaBounty and Horn, 1997). To a lesser degree, the flows through the SNWS pumping plant and Hoover Dam may influence the interflow characteristics. As a result, the findings from this field trip are applicable only for this set of flow conditions and reservoir stratification.



Ref: Janie Jo Smith (LC Region)

Figure 5. Hoover Dam releases (ft^3/sec) for August 3, 1999. The time period when ADCP transects were collected in Black Canyon is indicated with a box.

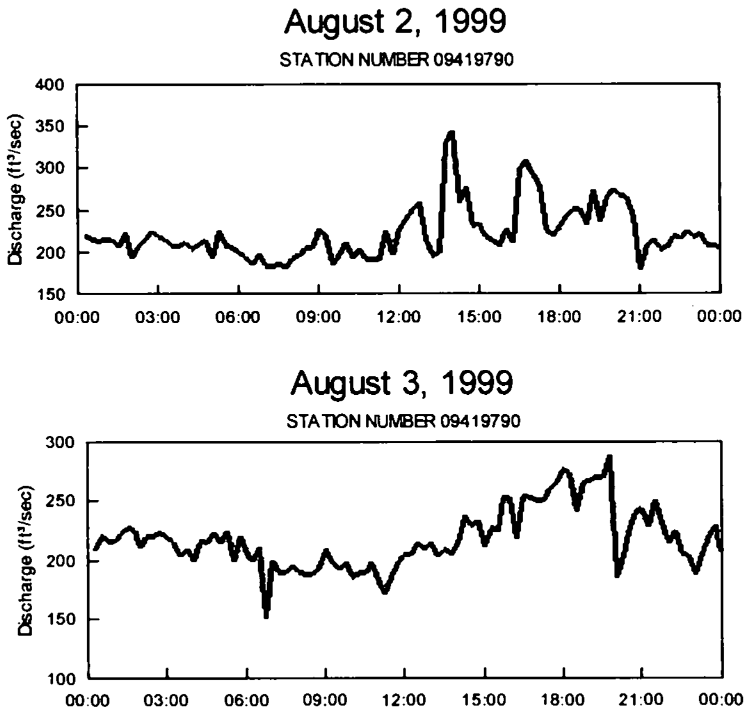


Figure 6. Las Vegas Wash hydrographs for August 2 and 3, 1999. This information was provided by the USGS for Station 09419790 and is provisional and subject to change.

Results

The ADCP was used to collect both velocity profiles and transects at several locations in Las Vegas Bay, Black Canyon, and near Hoover Dam. The ADCP and ADV instruments were used to measure velocity profiles within the Las Vegas Wash interflow at sampling stations LVB1.5, LVB1.8, LVB2.15, LVB2.6, LVB3.5, LVB4.15, LVB4.95, and LVB7.3. The site I.D.'s used in figure 2 also have a station I.D.'s based on river miles from the Las Vegas Bay inlet. Table 1 shows the two different notations for describing the sampling sites. For this report, Station I.D.'s will be used to reference sampling locations.

Table 1. Cross reference between sampling sites and stations used in this report.

Site I.D.	LV01	LV02	LV03	LV05	LV08	LV10	LV12	LV14
Station I.D.	LVB1.5	LVB1.8	LVB2.15	LVB2.6	LVB3.5	LVB4.15	LVB4.95	LVB7.3

The ADV stopped working when collecting data at LVB4.95, so data were not collected at this station or beyond. An examination afterwards revealed that the ADV probe became disconnected from the conditioning module resulting in the malfunction.

Both the ADV and ADCP report an acoustic backscatter signal strength which can be used to detect turbidity plumes and other scatterers in the water column. When a given layer of water contains a large number of scatterers, the amplitude of the backscattered signal increases. This information was used to determine the position of the interflow vertically and horizontally throughout Las Vegas Bay. The ability to detect the typical Las Vegas Wash interflow was complicated because of a second plume associated with recent flash floods in Las Vegas Wash. At profiling locations upstream from LVB2.15, the flood plume and the Las Vegas Wash interflow were nearly coincident. Likewise, discussions with Dr. LaBounty and Dr. Holdren brought to my attention that decaying organic particles and fine clays can accumulate within the thermocline. These particles will also generate high backscattered signals. For this set of data, all these factors combine to make isolating the Las Vegas Wash interflow a challenge.

ADCP Velocity Profiles - A summary of ADCP data which includes depth, speed ± RMS (root mean square deviation) and direction, and signal amplitude are presented in table 2. Each site can have two reported values – one for the depth of the peak velocity and another for the peak signal amplitude. In some cases these two depths coincide, as noted in the comments column. In general, the peak signal amplitudes corresponded very closely with peak specific conductance values collected by the limnologists. Several of the ADCP profiles had a high degree of uncertainty (large RMS deviations) because of the low velocity resolution of an ADCP velocity measurement. Another factor for the large uncertainty was the effects of boat motion caused by waves and boat wakes.

Table 2. Summary of ADCP Velocity Profile Data Collected in Las Vegas Bay

Site ID	Depth (meters)	V_{horiz} ± RMS (cm/sec)	Direction (° from North)	Signal Amp. (dB)	Comments
LVB1.5 (LV-01)	3.8	2.5 ± 6.5	247 ± 100	68.1	Peak vel. and Amp coincide
LVB1.8 (LV-02)	5.8 9.8	5.5 ± 38.7 5.5 ± 36.3	286 ± 105 324 ± 109	68.5 74.0	Peak Vel Peak Amp
LVB2.15 (LV-03)	12.8	9.1 ± 30.2	150 ± 87	74.6	Peak vel. and Amp coincide
LVB2.6 (LV-05)	12.8	9.1 ± 45.1	111 ± 93	68.5	Peak vel. and Amp coincide
LVB3.5 (LV-08)	9.8 12.8	6.3 ± 6.6 3.7 ± 5.2	276 ± 80 295 ± 103	65.7 70.4	Peak Vel Peak Amp
LVB4.15 (LV-10)	6.8 12.8	6.7 ± 22.6 2.7 ± 20.7	99 ± 99 249 ± 93	64.6 72.8	Peak Vel Peak Amp
LVB4.95 (LV-12)	8.8 12.8	16.0 ± 76.5 14.6 ± 78.0	148 ± 71 137 ± 90	69.4 75.9	Peak Vel Peak Amp
LVB7.3 (LV-14)	14.8 18.8	5.4 ± 5.1 2.8 ± 4.6	325 ± 124 51 ± 107	69.9 71.9	Peak Vel Peak Amp

ADV Profiles - A summary of ADV data which includes measurement depth, current speed ±RMS, and signal amplitude are presented in table 3. These data are the most accurate speed measurements collected inside the interflow. Each sampling site can have two reported values. One for the depth of the peak speed and another for the peak signal amplitude. A plot of the average horizontal speed and signal amplitude for station LVB-2.15 is shown in figure 7. The error bars represent the ±RMS values. This example illustrates how the peak speed and peak signal amplitude can occur at different depths. Like with the ADCP measurements, the peak signal amplitudes corresponded very closely with peak specific conductance values collected by the limnologists. Speed profiles were not collected at sites LVB4.95 and LVB7.3 because the ADV equipment malfunctioned.

A summary of all ADV velocity and signal amplitude profiles are included in the appendix of this report. The appendix also contains a table of the ADV data collected and related statistics.

Table 3. Summary of ADV Speed Profile Data Collected in Las Vegas Bay

Site ID	Depth (meters)	Speed$_{horiz}$ ± RMS (cm/sec)	Direction (° from North)	Signal Amp. (dB)	Comments
LVB-1.5	6.3	4.5 ± 2.3	N/A		Peak speed
(LV-01)	3.3			107	Peak Amp
LVB-1.8	11.0	6.5 ± 3.4	N/A		Peak Speed
(LV-02)	12.0			117	Peak Amp
LVB-2.15	10.0	14.2 ± 7.6	N/A		Peak Speed
(LV-03)	13.0			115	Peak Amp
LVB-2.6	13.0	7.3 ± 5.5	N/A		Peak Speed
(LV-05)	12.0			98	Peak Amp
LVB-3.5	11.0	5.2 ± 9.0	N/A		Peak Speed
(LV-08)	10.0	3.7 ± 5.2		90.0	Peak Amp
LVB-4.15	10.0	8.4 ± 5.2	N/A		Peak Speed
(LV-10)	9.0	2.7 ± 20.7		90.0	Peak Amp

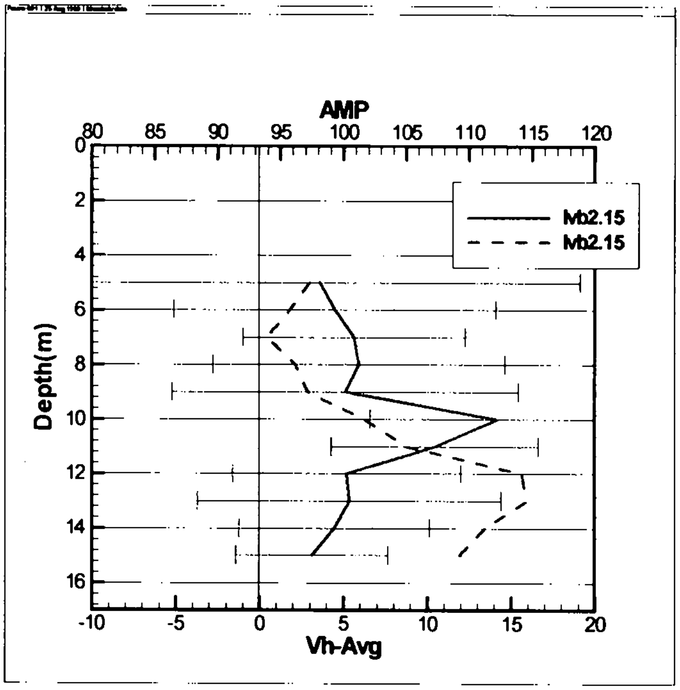


Figure 7. A typical plot of average horizontal speed (cm/sec, solid line) and signal amplitude (dB, dashed line) collected at station LVB2.15. The red bars are error bars representing the RMS deviation for each point measurement.

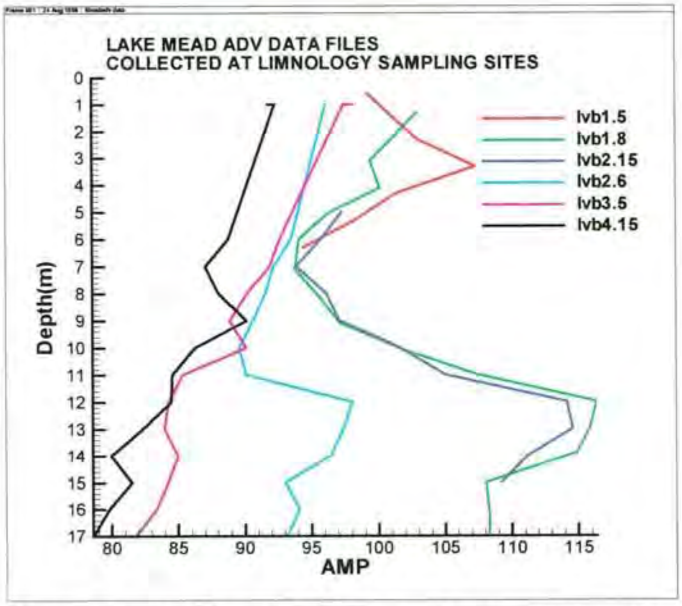


Figure 8. Profiles of ADV acoustic signal strength (AMP) for six sampling sites in Las Vegas Bay. Note how the vertical position of the interflow changes with distance travelled into the bay.

The variation in current speed from station to station is likely a function of waves and wind and the boat motion they create. When possible, the boat was anchored to minimize this motion, but rotation around the anchorage, caused by the wind or boat motion caused by waves, could not be prevented. Speed measurements will also vary with fluctuations in Las Vegas Wash discharge. Another reason for interflow speed variation is changes in channel width which changes the cross sectional area of the plume for a given cross section. Likewise, ADCP transect data indicate that the Las Vegas Wash interflow is concentrated toward the right bank or the southeast shoreline. Therefore, the interflow speed can vary from left bank to right bank, with higher speeds along the right bank.

Interflow Location - Using the amplitude of the ADV signal strength, the vertical extent of the interflow could be determined. Figure 8 shows the profiles of signal strength measured at LVB1.5, LVB1.8, LVB2.15, LVB2.6, LVB3.5 and LVB4.15. This figure shows how the interflow is located about 13 meters deep from station LVB1.8 to LVB2.6. Further into Las Vegas Bay, the interflow is centered about 10 meters deep. It is also apparent that the particles in the plume are settling out because the amplitude of the ADV signal is decreasing with distance traveled into Las Vegas Bayke Mead. The typical thickness of the interflow is about 4 to 5 meters. Remnants of the aforementioned floods are visible at lower depths. Conductivity profiles collected in front of the SNWS intake on July 16, 1999 (eight days after the flood) show a strong plume located between 11 and 16 meters deep (Roefer 1999). The interflow location was also quantified by August 2, 1999 specific conductivity profiles as is shown in figure 9. Likewise, the plume from the July 8, 1999 flood is also clearly indicated in conductivity data plotted in figure 9.

Interflow Travel Times - The ADV data were used to compute interflow travel times between sampling stations LVB1.5, LVB1.8, LVB2.15, LVB2.6, LVB3.5, and LVB4.15. The travel times (in hours) were calculated by dividing the number of river miles between stations by the average of the maximum interflow speeds measured at the two stations (converted to miles/hr) that are reported in table 3. The results of these computations are summarized in table 4. Using an average interflow speed of 0.15 miles per hour, I estimated the travel time between LVB4.15 to LVB4.95 to be 5.5 hours. Using an interflow speed of 0.15 miles per hour I estimated the travel time between LVB4.95 to LVB7.3 to be 14.2 hours. Similarly, using a speed of 0.15 miles per hour, the travel time between LVB7.3 to SNWS pumping plant intake was estimated to be 13.5 hours.

For this specific set of hydraulic conditions, the estimated travel time from LV1.5 to the SNWS pumping plant is about 49.5 hours. A similar travel time for the July 8, 1999 flood plume (~53 hours) was determined from measurements of turbidity in SNWS Intake raw water samples (Roefer 1999). Travel times will vary depending on Las Vegas Wash discharge which is the main factor in establishing the interflow speed. However, if the withdrawal zones of the Saddle Island pumping stations are at the same elevation as the interflow, pumping will most likely decrease the interflow's travel time. Likewise, during certain periods of the year and for certain reservoir levels, releases from Hoover Dam may impact the travel time of the Las Vegas Wash interflow.

Table 4. Travel time in hours between Las Vegas Bay sampling stations

Stations	LVB1.5 to LVB1.8	LVB1.8 to LVB2.15	LVB2.15 to LVB2.6	LVB2.6 to LVB3.5	LVB3.5 to LVB4.15
River Miles	0.30	0.35	0.45	0.90	0.65
Avg Speed (miles/hr)	0.12	0.23	0.24	0.14	0.15
Travel time (hrs)	2.50	1.52	1.87	6.43	4.33

ADCP Transects - ADCP transects were used to determine the lateral extent of the Las Vegas Wash interflow as it passes through Las Vegas Bay and into Boulder Basin. Transects were made by collecting ADCP data on a boat that was traversing from right bank to left bank or vice versa. In general, an ADCP profile was collected for every 5 meters of boat travel or once every 3 to 5 seconds. Both of these values vary with boat speed and water depth.

The ADCP signal strength was used in this study to document the position of the interflow both vertically and horizontally throughout Las Vegas Bay. The ability to detect the typical Las Vegas Wash interflow was complicated because of a second plume associated with recent flash floods in Las Vegas Wash. At many profiling locations the flood plume and the typical Las Vegas Wash interflow were nearly coincident. This was especially true at sampling sites closer to the Las Vegas Wash delta. At locations beyond LVB7.3, detecting the Las Vegas Wash interflow was made difficult because we could not determine if the particles were organic (from the reservoir) or were from Las Vegas Wash. On this date, the limnologists were not able to detect the interflow with their specific conductance probe at station LVB7.3, as shown in figure 9. ADCP signal strengths and specific conductance measurements were both good indicators for detecting the Las Vegas Wash interflow. However, the ADCP cannot differentiate between particles carried by the interflow and naturally occurring organics and clay particles that accumulate at the same depths. As result, it is necessary to collect ADCP data and conductivity profiles to accurately identify the interflow.

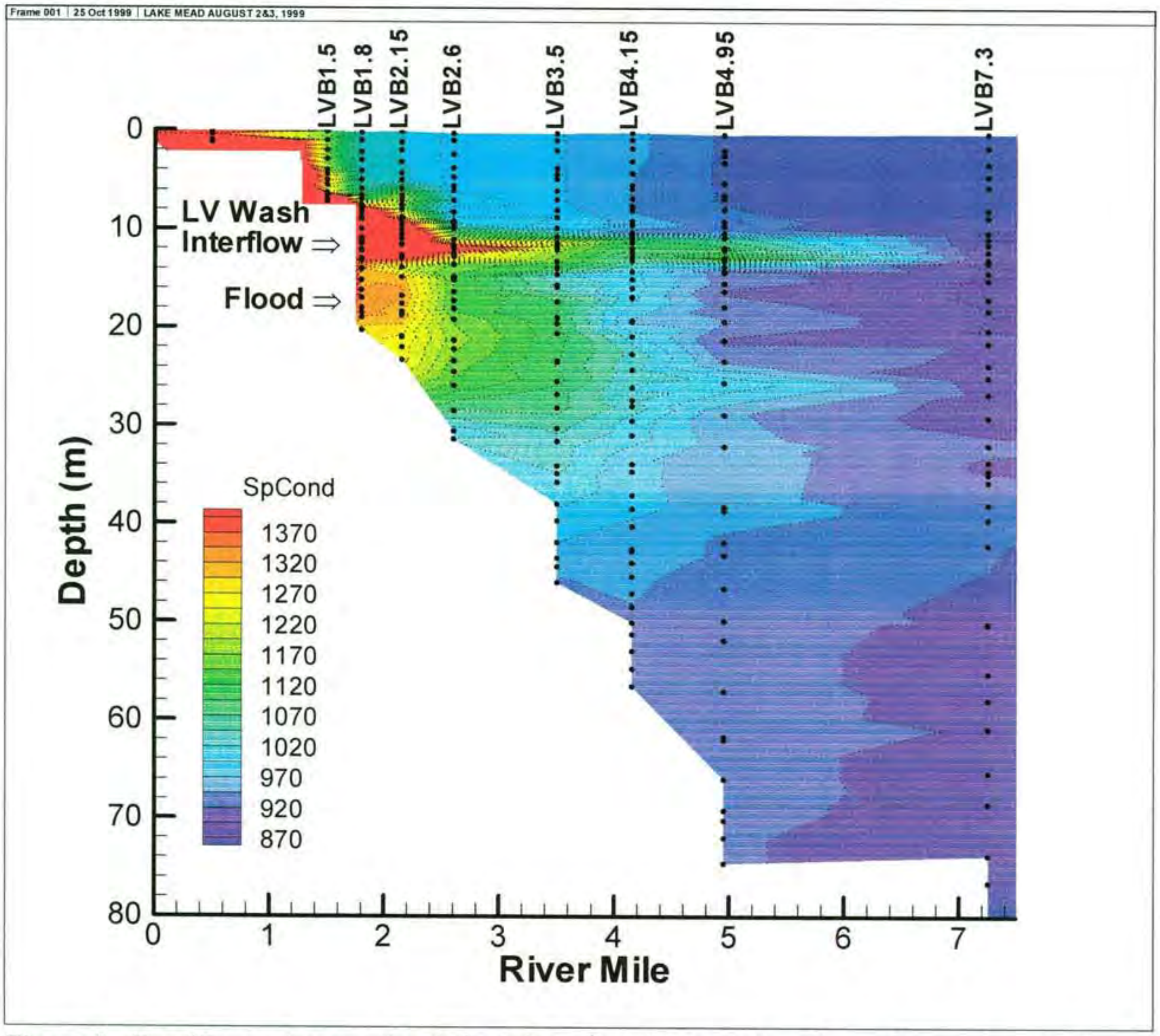


Figure 9. Specific conductance isopleths (uS·cm^{-1}) collected in Las Vegas Bay on August 2, 1999.

A summary of the ADCP transects collected in Las Vegas Bay and Boulder Basin is given below:

Figure 10 shows plots of ADCP signal strength data collected for a "Z-like" transect from LVB2.6 to the left bank to the opposite right bank and onto LVB3.5, and the temperature and conductivity profiles. The ADCP data shows the Las Vegas Wash interflow located 12 to 13 meters deep. It also shows that the interflow has a higher concentration of particles in the middle of the cross section between the left and right banks. The plot also shows a turbidity plume at depths below 20 meters which presumably is from the Las Vegas area flooding. This flood plume appears to be concentrated near the right bank. This observation is consistent with the plume being drawn toward areas of withdrawal from Lake Mead, namely the Saddle Island pumping plants and Hoover Dam. A comparison of ADCP signal strength and conductivity profiles shows that there is very good correlation for these two parameters. The temperature and conductivity profiles also show that the Las Vegas Wash interflow contained within the thermocline. The lower plume measured by the ADCP appears to be lower than the conductivity plume. It is important to remember that the ADCP signal strength is a function of the number and size of particles at a given depth, whereas the conductivity is a measure of the ionized materials in the water. It is possible that at this station the flood entrained particles have settled out to a certain depth, but the flood waters would still maintain its higher conductivity. This would also explain why the ADCP detected a higher concentration of particles near the reservoir bottom.

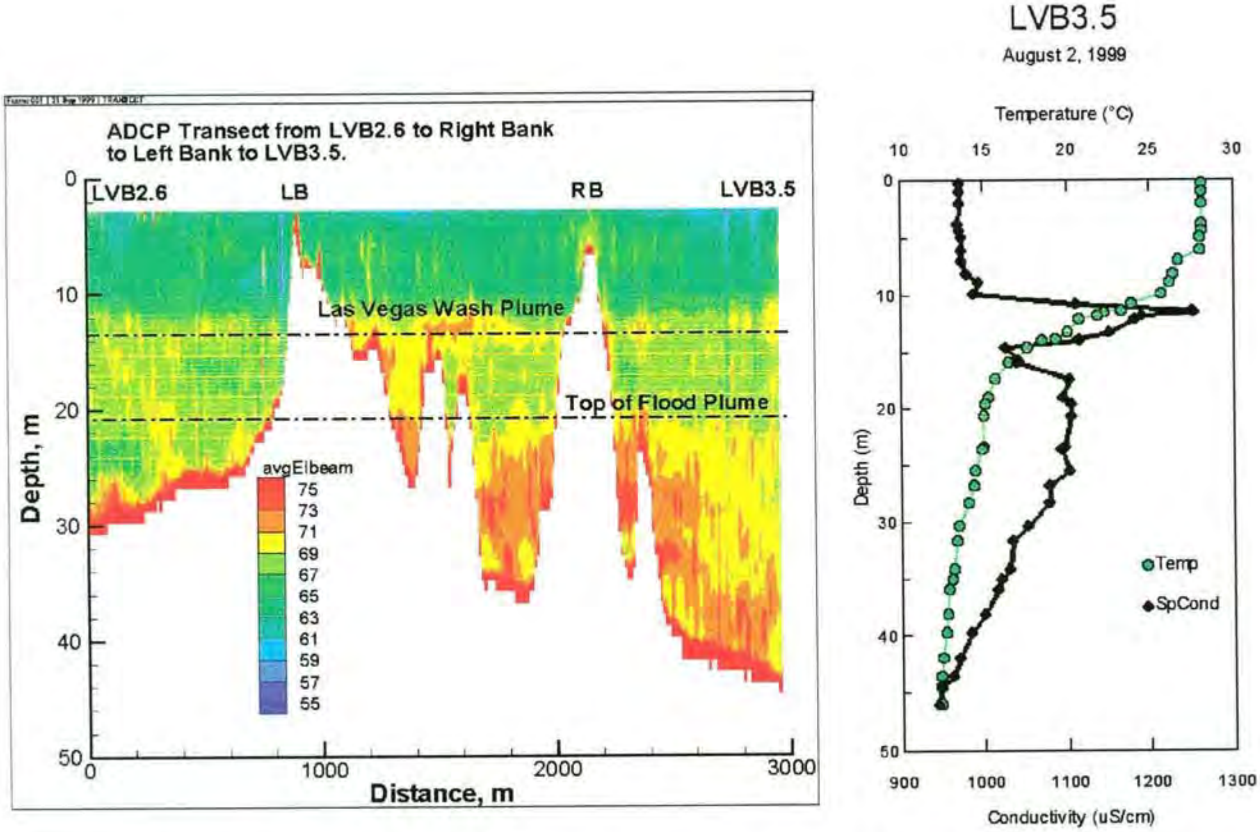


Figure 10. Plot of ADCP signal strength covering a transect from LVB2.6 to the left bank to the opposite right bank and onto LVB3.5. This plot shows the Las Vegas Wash interflow at 12 to 13 meters deep and a turbidity plume resulting from the Las Vegas flooding at depths below 20m. The plot on the right shows the temperature and conductivity profiles for station LVB3.5.

Figure 11 contains plots of ADCP signal strength data for a transect from LVB3.5 to the left bank to the opposite right bank and onto LVB4.15, and the temperature and conductivity profiles collected at LVB4.15. The ADCP data shows the Las Vegas Wash interflow is located 10 to 15 meters deep. Figure 11 shows that the interflow has a higher concentration of particles and is thicker in the right half of the cross section. The ADCP data show a turbidity plume at depths below 20 meters resulting from the Las Vegas area flooding. This flood plume appears to be more evenly distributed across the section when compared to figure 10. This observation is consistent with the plume being drawn toward areas of withdrawal from Lake Mead, namely the Saddle Island pumping plants and Hoover Dam. Again, the correlation between ADCP signal strength and the conductivity profiles is very good for both plumes. As at station LVB3.5, the vertical extent of the Las Vegas Wash interflow is contained within the thermocline. At this station, the lower extent of the flood plume is clearly visible at a depth of 35 meters on both plots.

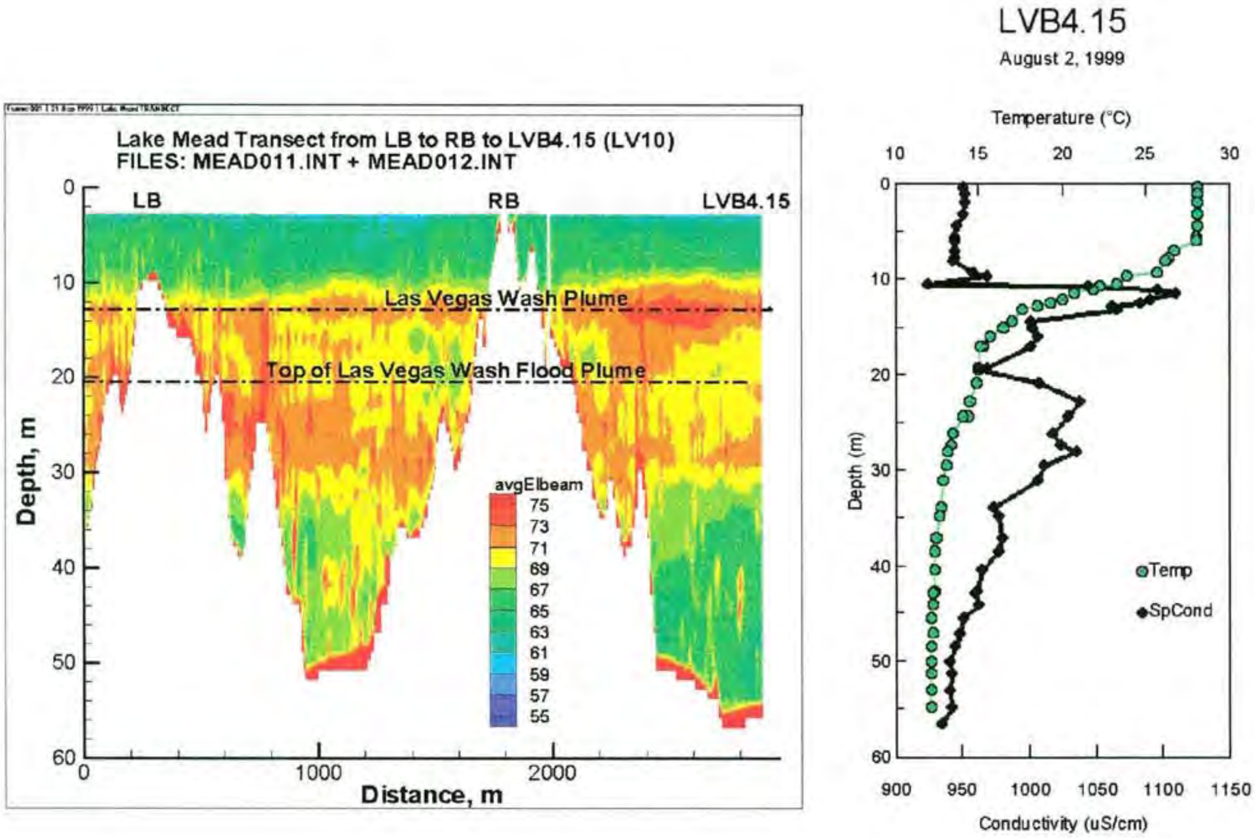


Figure 11. Plot of ADCP signal strength covering a transect from LVB3.5 to the left bank to the opposite right bank and onto LVB4.15. This plot shows the Las Vegas Wash interflow at 12 to 13 meters deep and a turbidity plume resulting from Las Vegas flooding at depths below 20m. The plot on the right shows the temperature and conductivity profiles for station LVB4.15.

Figure 12 shows plots of ADCP signal strength data for a transect from station LVB4.95 to the right bank (near red buoy no. 4) and the temperature and conductivity profiles collected at LVB4.95. The ADCP data shows the Las Vegas Wash interflow is located at between 9 to14 meters deep. The interflow detected with the ADCP agrees very closely with the conductivity plume shown in profile plot. Again, the Las Vegas Wash interflow is confined within the thermocline. The ADCP data shows the Las Vegas Flood plume appears to be concentrated near the right bank, and the vertical extent of the flood plume covers a range from about 20 to 30 meters deep. The conductivity profile also showed an elevated conductivity within the flood plume.

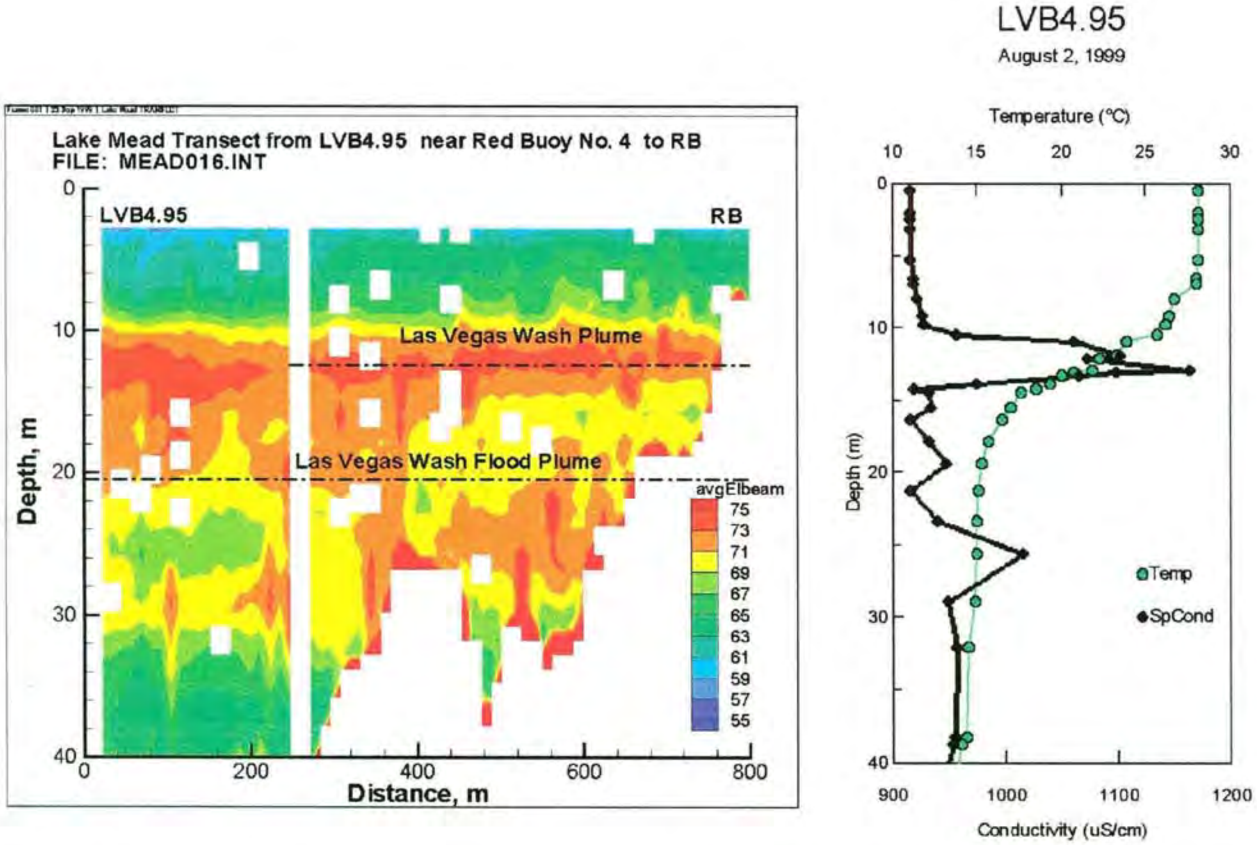


Figure 12. ADCP transect from LVB4.95 to the right bank. The plot on the right shows the temperature and conductivity profiles for station LVB4.95.

Figure 13 contains a plot of ADCP signal strength for a transect from the left bank through station LVB7.3 to the right bank (near green buoy no. 1), and the temperature and conductivity profiles collected at station LVB7.3. The ADCP signal strength data indicate that the Las Vegas Wash interflow is located 12 to 13 meters deep. The interflow is only about 1660 meters wide and is concentrated along the right bank. At LVB7.3 it was difficult to pick up the interflow in the conductivity profile – although there was a small increase in conductivity in the range of 12 to 13 meters deep. An increase in backscatter signal strength was observed within the limits of the thermocline (between 14 to 30 meters deep) over the entire transect width. Acoustic scatterers in this layer are most likely decaying organics which collect within the thermocline. For this transect, the signal strength data no longer show the flood plume. This observation is contrary to figures 10, 11, and 12 which showed the flood plume extended deeper than the lower limit of the thermocline. This indicates that the particles carried into Lake Mead during the July flood(s) may have settled out of the water column between stations LVB4.95 and LVB7.3 or may have been entrained into the Colorado River interflow. Another explanation may be that the flood plume did not have enough energy to reach station LVB7.3 and the elevated conductivities were coming from another source. It is also interesting that the conductivity profile shows a layer of higher conductivity water in the range of 30 to 50 meters; the source of this elevated conductivity is unknown.

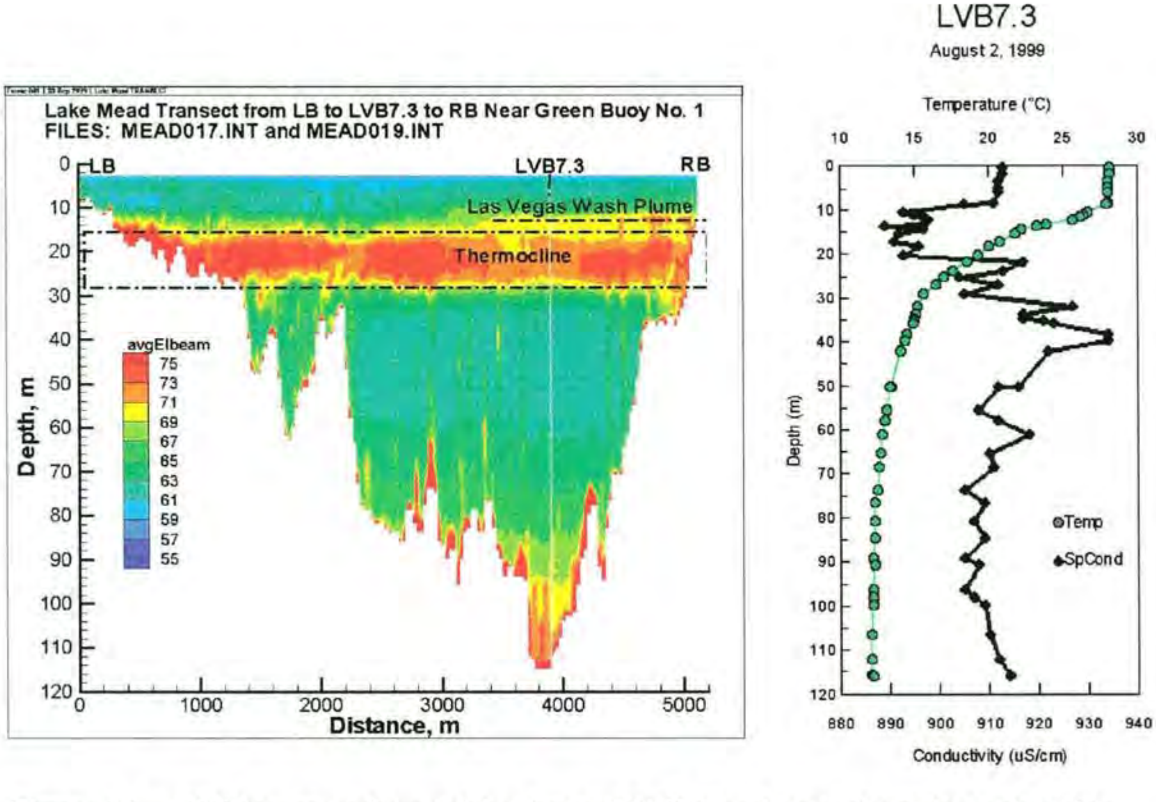


Figure 13. ADCP transect from left bank past LVB7.3 and on to the right bank which was near Green Buoy No. 1. The plot on the right shows the temperature and conductivity profiles for station LVB7.3.

ADCP Data Collected Near the SNWS Intake on Saddle Island - Several sets of ADCP transect and profile data were collected in the vicinity of the SNWS intake tunnel. This data collection activity was not part of the original scope of work, but was included because time permitted. The velocity profiles collected near the SNWS intake did not clearly show the intake's withdrawal zone. The ADCP can not accurately measure small velocities when the velocities are less than the boat velocity. Likewise, ADCP's cannot measure velocities near the reservoir bottom. During data collection, we had nothing to moor to so we could not eliminate boat motion. As a result, we were not able to accurately define the withdrawal characteristics of the SNWS intake on Saddle Island. However, in one case, velocities magnitudes on the order of 7 ± 5 cm/sec in a westerly direction were observed at depths from 50 to 60 meters for a profile collected near the intake. This profile was collected where the water was 75 meters deep. Figure 14 shows the highly variable velocities measured for the profile collected near the SNWS Intake. This figure also shows that the acoustic signal strength (dashed line) increases in the thermocline region and also between depths of 45 to 55 meters. If accurate intake velocities are needed in the future, I would suggest using an ADV to collect the velocity profiles. However, an ADV with a longer cable would have to be purchased to measure velocities at depths of 75 meters.

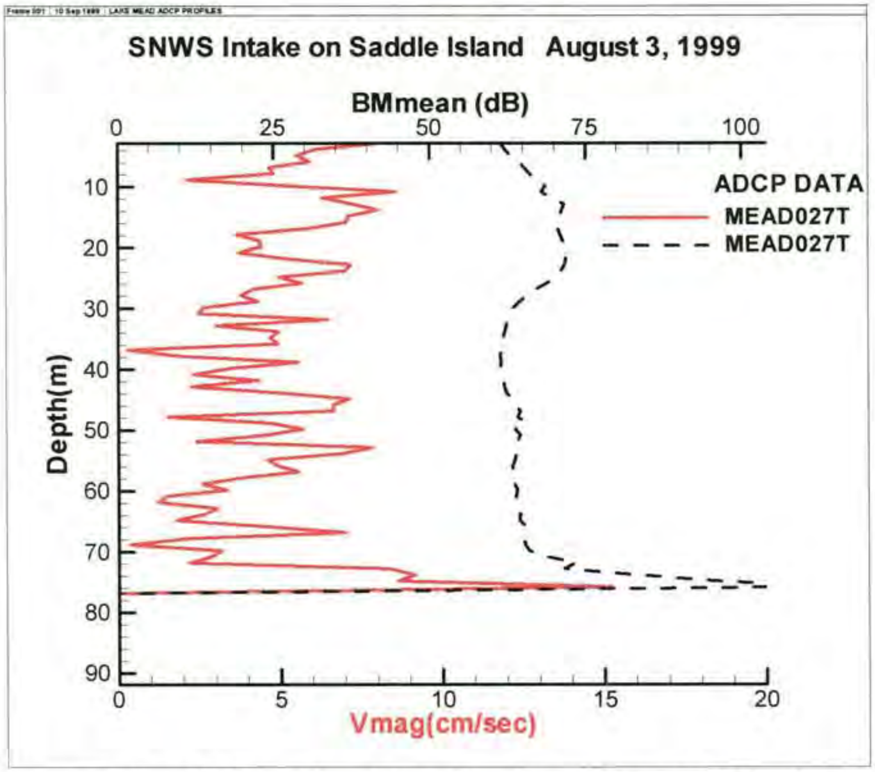


Figure 14. ADCP profile collected in front of the SNWS intake located on Saddle Island. The plot of velocity magnitudes do not clearly show a withdrawal zone generated by the intake. The dashed line is the mean signal strength profile.

ADCP transects collected in Black Canyon near Hoover Dam - Several ADCP transects were collected in Black Canyon in an effort to determine if withdrawals through Hoover Dam could be measured with the ADCP. This data collection activity was not part of the original scope of work, but was included because time permitted. The ADCP was able to measure velocities in part of the water column, but at depths greater than 80 meters the signal strength degraded to the point where they were marked as unreliable (or bad). Figure 15 shows the ADCP velocity data collected in a transect just upstream of the intake towers. Velocities in the range of 30 to 40 cm/sec were measured in the withdrawal zone. The estimated withdrawal zone for August 3, 1999 at about 1:00 p.m. is shown, but it probably extends into the region labeled "lost data." The combined flow through all four intake towers at this time was reported to be 990 m^3/sec (35,000 ft^3/sec). The elevations of the cylinder gates are indicated on the figure. It is my understanding the both cylinder gates are open during normal operations.

Figure 16 shows the ADCP's acoustic signal strength for the same transect collected in front of the intake towers and the temperature and conductivity profiles collected at LV-17. The signal strength shows a high concentration of scatterers in the thermocline which is consistent with what was observed at LVB7.3. The conductivity profile collected at site LV-17 had three peaks in conductivity below the thermocline the source of each is unknown.

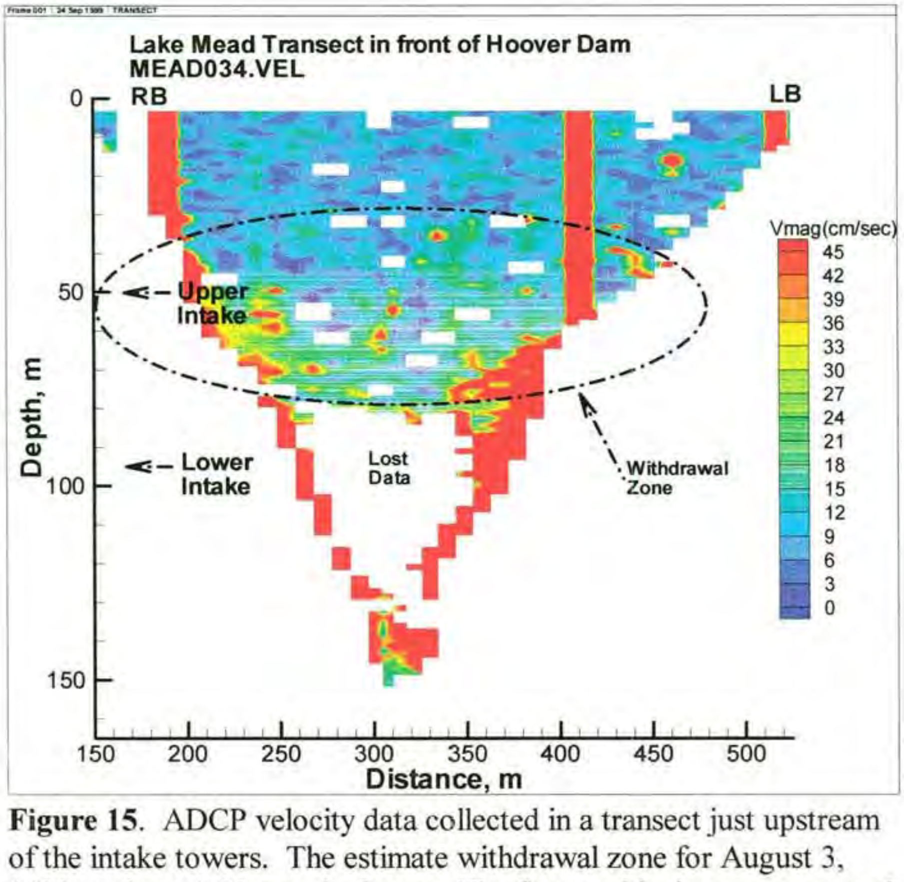


Figure 15. ADCP velocity data collected in a transect just upstream of the intake towers. The estimate withdrawal zone for August 3, 1999 at about 1:00 p.m. is shown. The flow at this time was reported to be 35,000 ft^3/sec.

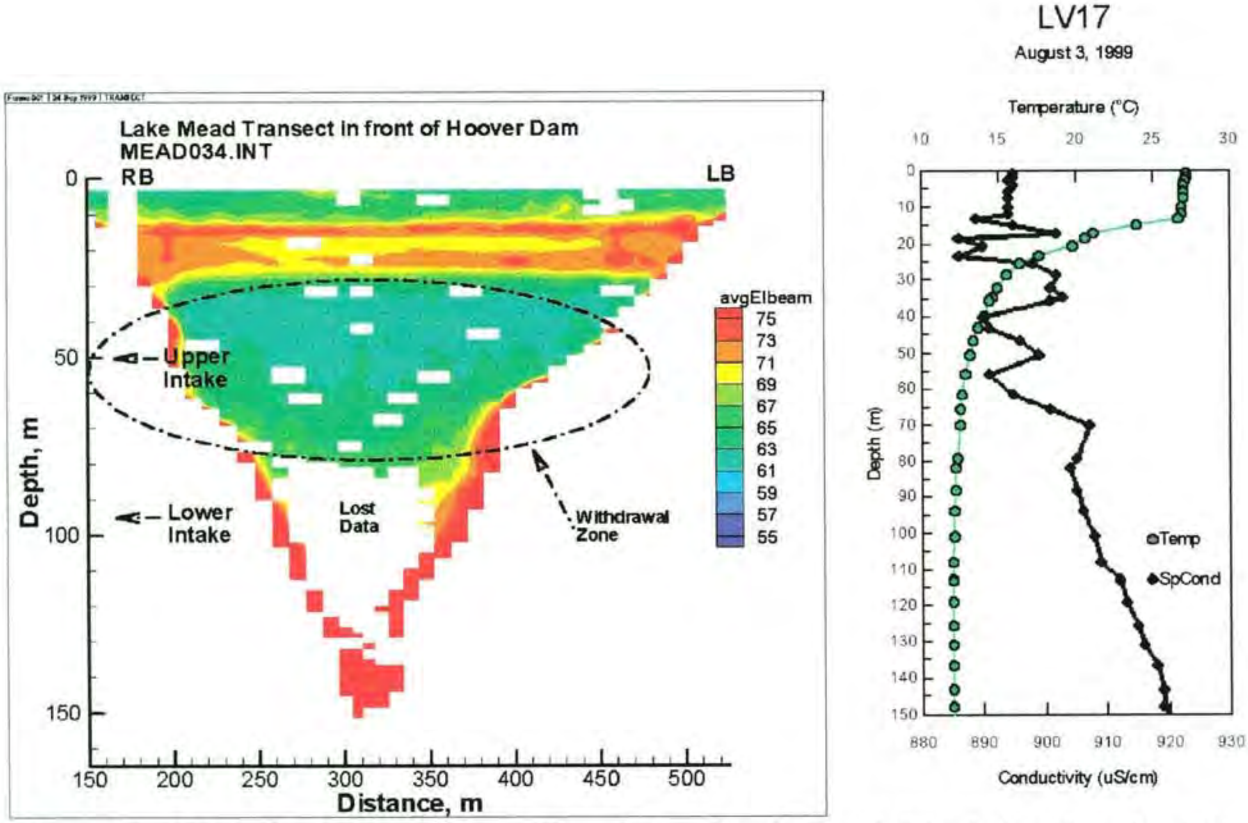


Figure 16. ADCP signal strength data collected from right bank to left bank directly in front of Hoover Dam. The plot on the right shows the temperature and conductivity profiles for station LV-17.

Data Summary

- The ADCP and ADV data collected in Boulder Basin were used to describe the characteristics of the Las Vegas Wash interflow. ADCP data were used to describe the spatial and vertical extent of the interflow as it flows into Boulder Basin. ADV data were collected in the interflow to determine the velocity profile and to calculate travel times. ADV data were also indicated that the number of particles in the Las Vegas Wash interflow decrease with distance into Las Vegas Bay.

- ADCP signal strength data showed the Las Vegas Wash interflow was located at an average depth of about 13 meters. From stations LVB-1.5 to LVB-3.5 the interflow appears to concentrated in the center of Las Vegas Bay. Further into Lake Mead, from stations LVB-4.15 to LVB-7.3, the interflow is concentrated along the right bank or southeast shoreline, see figure 17. The interflow was typically 4 to 5 meters thick.

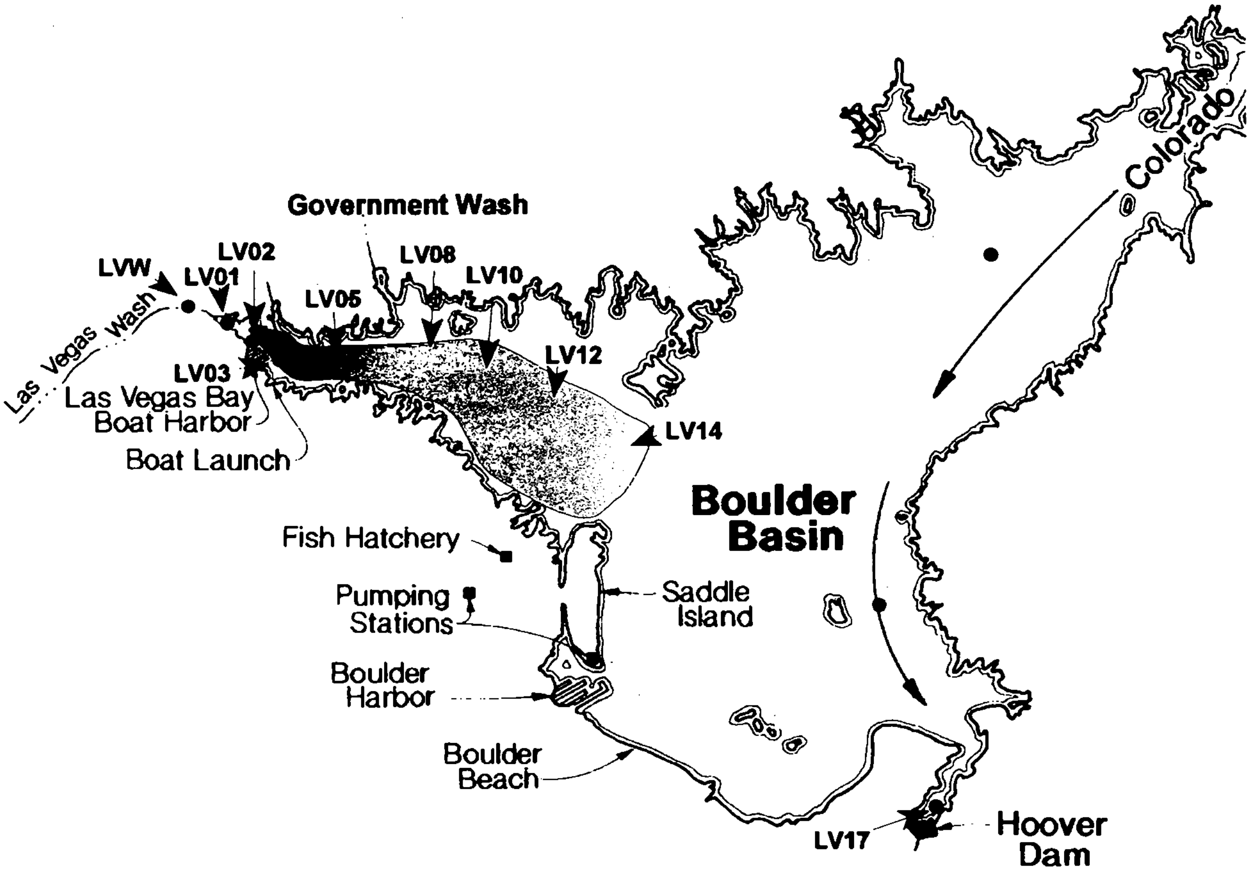


Figure 17. Estimated interflow extents based on signal strength data collected during ADCP transects.

- ADCP signal strength and conductivity measurements were both good indicators of the Las Vegas Wash interflow. However, while the ADCP seems to be a more sensitive measure of interflow presence, the ADCP cannot differentiate between particles carried by the interflow and naturally occurring organics that accumulate at the same depths. As result, it is necessary to collect ADCP data and conductivity profiles to accurately identify the Las Vegas Wash interflow.

- Flash floods which occurred July 8, 1999 created large turbidity and conductivity plumes which were detected by both the ADCP and specific conductance measurements. On August 2, 1999, the flood plume extended to station LVB4.15. The vertical extents of the flood plume were between 15 to 30 meters deep.

- Velocities inside the interflow, measured with an ADV, ranged from 5 to 14 cm/sec. Using these velocities, the travel time between stations LVB1.5 to LVB4.15 was estimated to be 16.6 hours. For this set of flow conditions, the travel-time between LVB1.5 to SNWS's pump intakes was estimated to be 49.5 hours. This estimate is based on assumptions about the interflow velocities in the outer limits of Las Vegas Bay which need further investigation. This travel time estimate was substantiated by SNWS personnel using time-series turbidity measurements collected at the SNWS Intake following the July 8, 1999 flood event (Roefer 1999)

- ADCP velocity measurements made in the vicinity of the SNWS intakes were inconclusive because of low approach velocities, and relatively high boat velocities caused by the wind. If this data is needed, an ADV will have to be used to measure these low velocities.

- ADCP velocity measurements collected in Black Canyon and near Hoover Dam detected the withdrawal zone velocities created by the penstock intakes. However, velocity data quality decreased with depth and the data were deemed unreliable at depths greater than 80 meters. ADCP signal strength data indicated a high concentration of particles in the thermocline, but the particles are probably decaying organics and not particles associated with the Las Vegas Wash interflow.

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Appendix

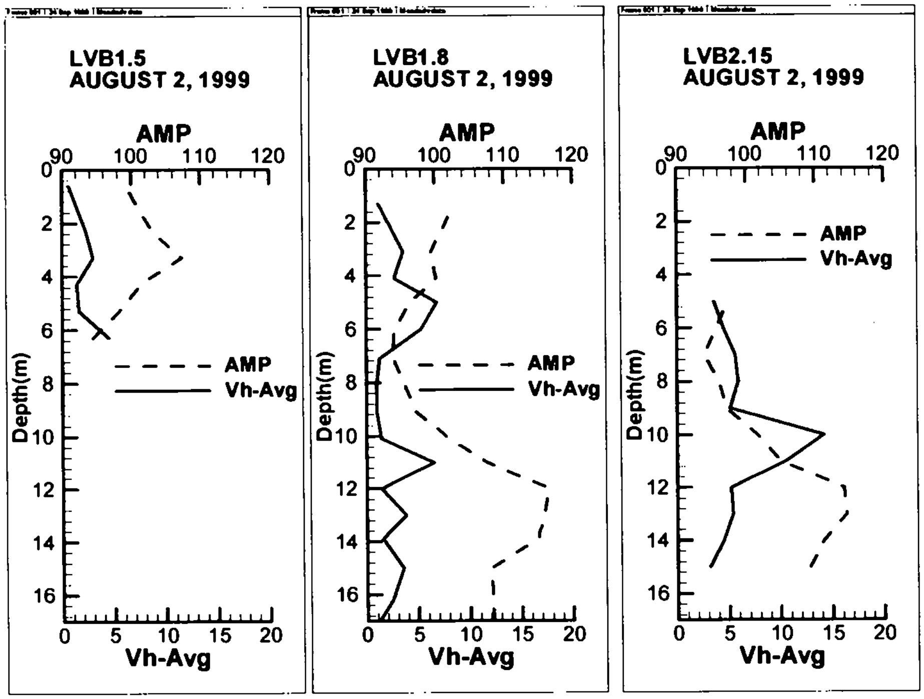

Figure 18. Plot of ADV signal amplitude and horizontal speed collected in the Las Vegas Wash interflow at stations LVB1.5, LVB1.8, and LVB2.15.

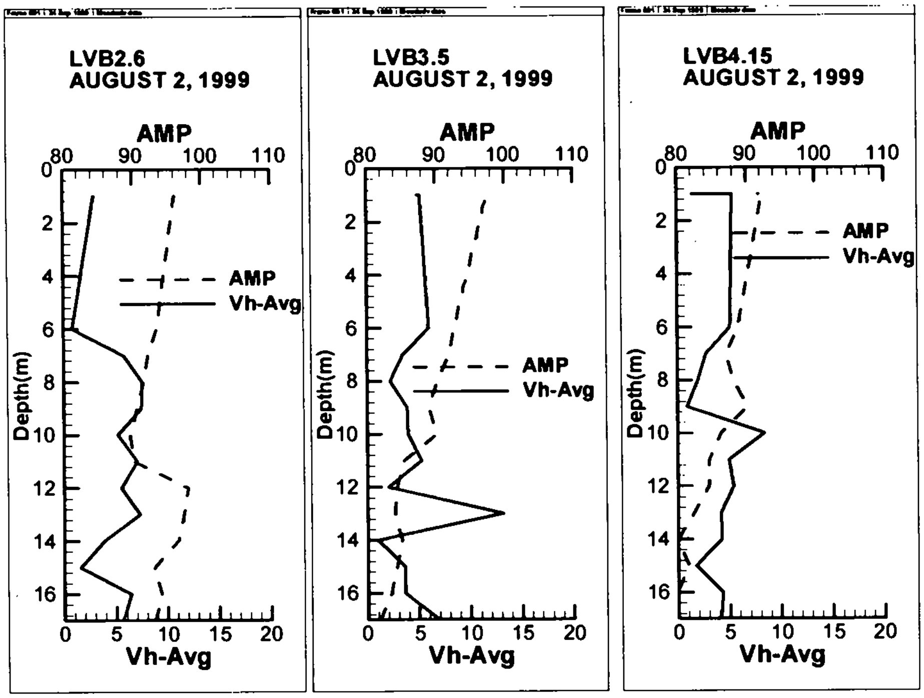

Figure 19. Plots of ADV signal amplitude and horizontal speed collected in the Las Vegas Wash interflow at stations LVB2.6, LVB3.5, and LVB4.15.

Table A1. Summary of ADV velocity data collected at Lake Mead on August 2, 1999
Processed by: WinADV32 - Version 1.835 (June 25, 1999)

File	depth meters	Avg Vx cm/sec	Avg Vy cm/sec	Avg Vz cm/sec	Avg Vhoriz cm/sec	Avg Vmag cm/sec	RMS[Vx'] cm/sec	RMS[Vy'] cm/sec	RMS[Vz'] cm/sec	|RMS[V']| cm/sec	RMS[Vh-mag'] cm/sec	COR %	SNR dB	AMP Counts
lvb15	6.30	-1.81	4.11	-2.15	4.49	5.96	2.31	2.25	1.42	3.52	3.22	96.71	17.53	94.43
lvb15	5.30	-0.94	-1.30	-1.97	1.60	3.52	1.67	1.84	1.42	2.86	2.48	97.13	19.18	98.26
lvb15	4.30	-1.31	-0.45	-1.55	1.39	3.56	2.08	2.63	1.33	3.80	3.34	97.56	20.52	101.38
lvb15	3.30	-0.87	-2.86	-1.71	2.99	4.08	1.54	1.95	1.50	2.90	2.48	97.25	23.08	107.34
lvb15	2.30	-0.98	-2.07	-1.56	2.29	3.28	1.18	1.49	1.15	2.21	1.89	97.69	21.22	103.01
lvb15	0.60	-0.80	-0.16	-1.19	0.62	3.56	2.54	2.43	1.19	3.71	3.52	97.44	19.60	99.25
lvb18	17.10	-0.41	-0.92	-2.80	1.01	3.56	1.19	1.08	2.21	2.74	1.61	98.25	24.93	108.31
lvb18	16.20	-1.43	-2.02	-3.57	2.47	6.58	3.49	3.74	2.28	5.60	5.12	97.89	24.93	108.31
lvb18	15.00	-2.99	1.90	-1.69	3.54	4.46	2.39	0.94	1.09	2.79	2.57	98.81	24.83	108.08
lvb16	13.90	0.18	-1.55	-1.72	1.56	4.31	3.71	1.28	1.22	4.11	3.92	98.89	27.75	114.88
lvb18	13.00	-1.26	-3.59	-1.18	3.80	4.95	2.66	2.41	0.89	3.70	3.59	98.91	28.17	115.84
lvb18	12.00	-0.52	-1.34	-1.71	1.44	4.77	3.65	3.21	1.34	5.05	4.86	98.60	28.40	116.39
lvb18	11.00	-4.90	-4.29	-2.85	6.51	7.54	2.78	1.94	2.05	3.98	3.39	98.27	24.58	107.50
lvb18	10.10	-0.78	-1.22	-1.55	1.45	3.83	2.54	2.37	1.24	3.68	3.47	98.41	22.23	102.02
lvb18	9.10	0.89	-0.47	-1.61	1.01	3.98	3.26	1.54	1.37	3.85	3.61	98.35	20.16	97.22
lvb18	8.10	-0.48	0.85	-1.72	0.98	3.24	2.39	1.00	1.27	2.89	2.59	96.40	19.46	95.59
lvb18	7.10	0.66	-1.10	-1.40	1.28	3.06	2.03	1.45	0.99	2.69	2.49	98.33	18.70	93.83
lvb16	6.00	5.21	1.07	-2.64	5.32	8.43	5.08	4.12	1.80	6.79	6.54	97.59	18.82	94.10
lvb18	5.00	4.69	4.98	-2.52	6.84	7.94	2.13	2.10	2.11	3.66	2.99	97.93	19.82	96.42
lvb18	4.10	0.52	2.67	-2.41	2.72	5.22	1.92	3.75	1.67	4.53	4.21	97.83	21.43	100.18
lvb18	3.10	-1.03	3.45	-2.38	3.60	5.06	1.92	1.57	1.60	2.95	2.48	98.29	21.11	99.43
lvb18	1.30	-1.12	-0.45	-2.46	1.21	6.93	5.62	3.30	2.27	6.90	6.52	97.01	22.65	103.00
lvb215	15.00	2.58	1.76	-6.71	3.12	9.01	3.19	3.23	4.72	6.55	4.54	90.01	25.33	109.24
lvb215	14.00	-4.11	1.75	-5.47	4.47	9.16	3.41	4.55	4.10	7.01	5.69	91.65	26.20	111.25
lvb215	13.00	-2.23	4.88	-4.82	5.37	10.84	6.47	6.32	3.44	9.68	9.04	93.16	27.63	114.58
lvb215	12.00	-4.06	3.24	-6.45	5.19	11.11	4.74	4.88	4.71	8.27	6.80	90.27	27.45	114.16
lvb215	11.00	-8.84	5.57	-3.60	10.45	12.58	4.98	3.66	3.40	7.05	6.18	94.33	23.52	105.04
lvb215	10.00	-6.39	12.65	-4.13	14.17	16.37	5.78	4.91	3.26	8.25	7.58	94.07	22.07	101.65
lvb215	9.00	-3.01	4.14	-7.40	5.12	12.64	5.27	8.88	4.84	11.40	10.33	88.39	20.13	97.15
lvb215	8.00	-5.53	-2.10	-7.55	5.92	13.17	5.14	7.03	5.93	10.53	8.71	88.98	19.71	96.18
lvb215	7.00	1.92	-5.30	-6.74	5.64	11.29	4.88	4.50	4.56	8.05	6.64	89.44	18.74	93.92
lvb215	6.00	-2.31	-3.86	-6.90	4.50	12.73	5.47	7.91	5.66	11.16	9.62	89.76	19.53	95.75
lvb215	5.00	-2.47	-2.62	-7.97	3.60	13.13	8.39	13.05	5.78	16.55	15.51	88.20	20.21	97.33
lvb26	17.00	-5.43	1.58	-4.41	5.66	8.25	2.28	2.86	3.04	4.76	3.66	93.04	18.27	93.15
lvb26	18.00	-6.23	1.63	-4.38	6.44	9.42	4.04	3.79	3.31	6.45	5.54	92.60	18.67	94.09
lvb26	15.00	1.54	-0.25	-6.06	1.56	7.70	2.30	3.48	3.75	5.61	4.17	90.99	18.22	93.04
lvb26	14.00	0.55	3.80	-4.65	3.84	9.17	6.09	8.40	4.17	11.18	10.38	93.75	19.70	96.48
lvb26	13.00	-6.73	-2.92	-5.80	7.34	11.17	3.20	4.51	3.98	6.61	5.53	89.70	20.09	97.39
lvb26	12.00	-5.45	-0.97	-6.67	5.54	10.85	4.29	4.12	4.62	7.53	5.95	88.71	20.37	98.04
lvb26	11.00	-6.66	2.42	-4.37	7.09	10.75	4.45	6.02	3.06	8.09	7.49	91.77	16.97	90.14
lvb26	10.00	-5.21	-0.29	-4.46	5.22	8.47	2.72	3.92	3.30	5.80	4.77	92.80	16.74	69.60
lvb26	9.00	-5.75	-4.84	-4.32	7.52	9.62	2.80	2.93	3.14	5.13	4.05	93.39	17.19	90.65
lvb26	8.00	-5.63	-5.08	-3.94	7.58	10.07	3.98	3.55	2.91	6.08	5.33	93.41	17.60	91.59
lvb26	7.00	-0.26	-5.60	-4.36	5.61	10.79	5.71	6.01	3.34	8.94	8.29	93.42	17.66	92.20
lvb26	6.00	-0.51	-0.66	-4.18	0.63	6.96	3.71	4.98	2.97	6.86	6.21	93.96	18.43	93.53
lvb26	1.00	2.77	1.04	-5.72	2.96	6.60	2.66	4.73	3.56	6.50	5.43	91.35	19.56	96.15

Table A1 (cont.) Summary of ADV velocity data collected at Lake Mead on August 2, 1999

File	depth	Avg	Avg	Avg	Avg	Avg						Span of 95%	pan of 95%	
		Vx	Vy	Vz	Vhoriz-Avg	Vmag	RMS[Vx']	RMS[Vy']	RMS[Vz']	|RMS[V']|	RMS[Vh-mag']	COR	SNR	AMP
	meters	cm/sec	cm/sec	cm/sec	cm/sec	cm/sec	cm/sec	cm/sec	cm/sec	cm/sec	cm/sec	%	dB	Counts
lvb35	17.00	-5.17	4.58	-4.14	6.91	9.03	2.07	2.80	3.01	4.60	3.48	92.53	13.52	81.77
lvb35	16.00	-3.17	1.79	-5.81	3.64	8.48	2.57	3.58	3.64	5.72	4.41	90.36	14.21	83.37
lvb35	15.00	-3.60	-0.04	-5.58	3.60	7.78	2.00	2.41	3.92	5.01	3.13	91.98	14.58	84.23
lvb35a	14.00	0.06	1.01	-6.80	1.01	9.56	7.06	9.68	4.15	12.68	11.98	85.38	14.91	85.00
lvb35a	13.00	13.12	-0.93	-6.90	13.15	30.65	35.55	5.41	3.35	36.11	35.96	84.24	14.47	83.97
lvb35a	12.00	1.84	0.85	-6.86	2.03	13.93	18.57	5.20	4.30	19.76	19.28	84.78	14.61	84.30
lvb35a	11.00	-0.08	-5.24	-5.12	5.24	10.06	5.84	6.90	3.78	9.80	9.04	84.72	15.07	85.37
lvb35a	10.00	1.11	-3.80	-5.20	3.96	10.84	6.32	9.56	3.48	11.98	11.46	83.44	17.12	90.14
lvb35a	9.00	0.43	-3.85	-4.53	3.87	9.78	6.01	9.13	3.47	11.47	10.93	87.84	16.59	88.91
lvb35a	8.00	1.11	-1.92	-5.00	2.22	7.54	3.61	5.15	3.38	7.14	6.29	84.31	17.15	90.21
lvb35a	7.00	3.45	-0.23	-4.35	3.46	10.37	5.77	10.85	3.21	12.70	12.29	86.19	17.88	91.92
lvb35a	6.00	3.25	-5.04	-3.81	6.00	9.37	2.62	6.20	2.75	7.27	6.73	87.18	18.21	92.67
lvb35a	1.00	-5.04	-1.23	-3.65	5.19	7.14	2.39	2.05	3.05	4.38	3.15	88.65	20.29	97.52
lvb35a	1.00	-4.89	-0.59	-2.73	4.93	6.37	2.02	2.27	1.95	3.61	3.04	90.11	20.55	98.13
lvb415	17.00	-3.98	-1.15	-1.93	4.14	4.85	0.66	0.97	1.41	1.84	1.17	93.25	12.73	78.60
lvb415	16.00	-1.76	-3.90	-3.33	4.28	5.90	1.34	1.23	2.31	2.94	1.82	91.19	13.24	79.80
lvb415	15.00	-0.38	-1.66	-3.28	1.70	7.34	4.42	6.96	2.21	8.54	8.24	88.47	13.98	81.52
lvb415	14.00	-0.06	-4.20	-3.31	4.20	5.94	1.64	1.45	2.15	3.07	2.19	90.71	13.32	79.97
lvb415	13.00	-1.95	-3.67	-2.89	4.16	8.76	7.15	7.94	2.18	10.91	10.68	89.31	14.34	82.35
lvb415	12.00	-1.35	-5.21	-2.90	5.38	8.49	5.96	4.71	2.34	7.94	7.60	90.62	15.26	84.49
lvb415	11.00	-0.68	-4.91	-3.37	4.96	7.59	3.85	2.76	2.29	5.26	4.74	89.86	15.30	84.58
lvb415	10.00	-1.51	-8.25	-3.31	8.39	10.07	4.89	1.81	2.21	5.66	5.21	91.46	16.03	86.28
lvb415	9.00	-0.71	0.54	-5.56	0.89	8.40	5.98	6.44	3.71	9.54	8.79	85.44	17.70	90.16
lvb415	8.00	-0.65	-1.86	-7.52	1.97	14.62	15.55	16.60	4.55	23.19	22.75	84.41	16.80	88.07
lvb415	7.00	1.29	2.41	-5.71	2.73	12.76	9.05	15.21	4.03	18.15	17.70	87.94	16.37	87.07
lvb415	6.00	-4.38	2.61	-5.62	5.10	11.44	8.95	10.61	3.85	14.40	13.88	87.97	17.11	88.79
lvb415	1.00	-3.78	3.74	-3.22	5.32	9.21	4.30	5.56	2.46	7.45	7.03	86.68	18.63	92.33
lvb415	1.00	-1.75	4.42	-3.29	4.75	7.93	3.59	4.53	2.34	6.24	5.78	87.76	18.45	91.90
lvb415	1.00	-0.61	1.34	-3.35	1.47	5.43	2.48	3.10	2.19	4.53	3.97	87.82	18.58	92.21
lvb415	1.00	-1.11	2.17	-2.79	2.44	10.66	6.66	9.19	2.24	11.57	11.35	87.36	18.41	91.80