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Hydraulic Characteristics of a Plunge Zone in Whiskeytown Reservoir, California

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1. Abstract

This paper presents field tests that were conducted to determine the hydraulic characteristics of a plunge zone. The field tests were carried out in Whiskeytown Reservoir which is part of the US Bureau of Reclamation's (Reclamation) Central Valley Project in northern California. Plunging inflows occur when cold water diverted from an upstream reservoir is discharged through a powerplant and into the thermally stratified reservoir. After plunging beneath the surface water, the density current travels downstream along the submerged thalweg, thereby producing stratified flow.

Velocity and temperature profiles were collected to quantify the hydraulic and thermal characteristics within the plunge zone. Velocity data were collected using a RD Instruments 600 kHz acoustic Doppler current profiler (ADCP). The boat-mounted ADCP was used to collect velocity profiles and to measure 12 cross sectional areas on both sides of the plunge zone. The plunge location was tracked visually and by monitoring the water temperature measured on the face of the ADCP transducer.

2. Introduction

Field tests were conducted to determine the hydraulic characteristics of a plunge point in Whiskeytown Reservoir, which is a component of the Shasta and Trinity Division of Reclamation's Central Valley Project in northern California (figure 1). This reservoir is situated near the divide between the Trinity and Sacramento River Basins. Whiskeytown Reservoir receives water from Trinity Lake via Lewiston Reservoir and Carr Powerplant. Water is passed through Whiskeytown Reservoir and is released through Spring Creek Powerplant, the reservoir's principal outlet. Releases are also made to the downstream reach of Clear Creek, the natural water course of the reservoir. The reservoir is normally operated with minimal water level fluctuation with inflow equal to outflow. However, flows do fluctuate with power demand on a daily 12-hour on- and off-peak generation cycle.

The cold water passing through Carr Powerplant enters the thermally stratified reservoir and normally forms an underflow after plunging beneath the warmer surface water. This intermittent insertion of a high energy cold water discharge slides beneath the warmer reservoir water forming an underflow that may maintain its integrity or will gradually mix with the surrounding water depending on the temperature gradient and the internal amount of turbulence.

This paper describes the results from two field tests that were carried out in June of 1996 to measure the hydraulic characteristics of the plunge point.

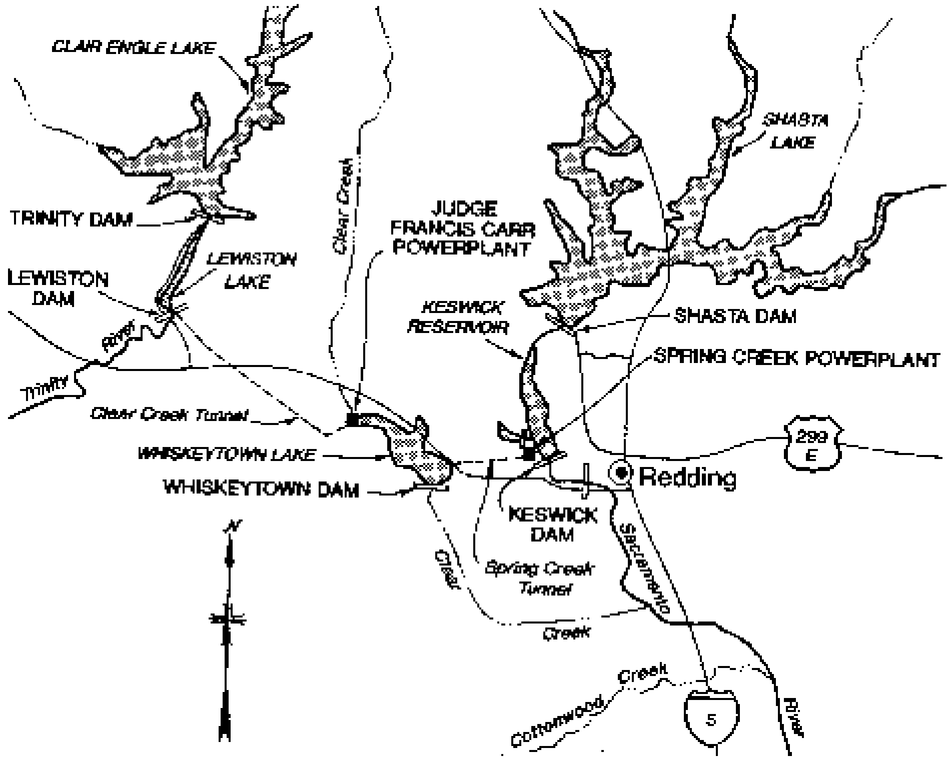

Figure 1. Location map of Whiskeytown Reservoir and part of the Central Valley Project in northern California, USA.

3. Definition of the Plunge Point

When a fluid of a given density moves into a fluid of slightly different density, it might enter as an underflow, interflow or overflow, depending on the density difference. This is normally referred to as a density or gravity current. Density differences can be generated by temperature, dissolved substances or suspended particles. When density currents enter a reservoir they plunge beneath the surface water and travel downstream along the submerged thalweg. The zone where the inflow enters a reservoir and plunges beneath the ambient water, thereby producing stratified flow, is called the plunge point or plunge zone.

The location of the plunge point is determined by a balance between the stream momentum and the pressure gradient across the interface that separates the inflow and reservoir water and the resisting shear forces. The location of the plunge zone can also be influenced by morphological factors (bed slope, bed friction, and cross-sectional area). The plunge location can be highly dynamic; it can move several kilometers in a few hours in response to dynamic flow events such as storm events or hydro power generation. Some mixing occurs at the plunge point because of eddies which develop by flow reversals and pooling of the inflow. After the inflow plunges, it usually follows the submerged river thalweg as an underflow. The speed and thickness of the underflow is determined by a balance between shear forces and the acceleration due to gravity.

The primary reason for studying the headwaters of Whiskeytown Reservoir was the plunge zone was influenced by a temperature control curtain that was installed in 1993 (Vermeyen 1997). The curtain is located near the Oak Bottom marina and campground which is about 4 km downstream from the Carr Powerplant (figure 2). Reclamation installed the Carr tailrace curtain to minimize mixing by controlling the amount of warm surface water supplied to the plunge zone.

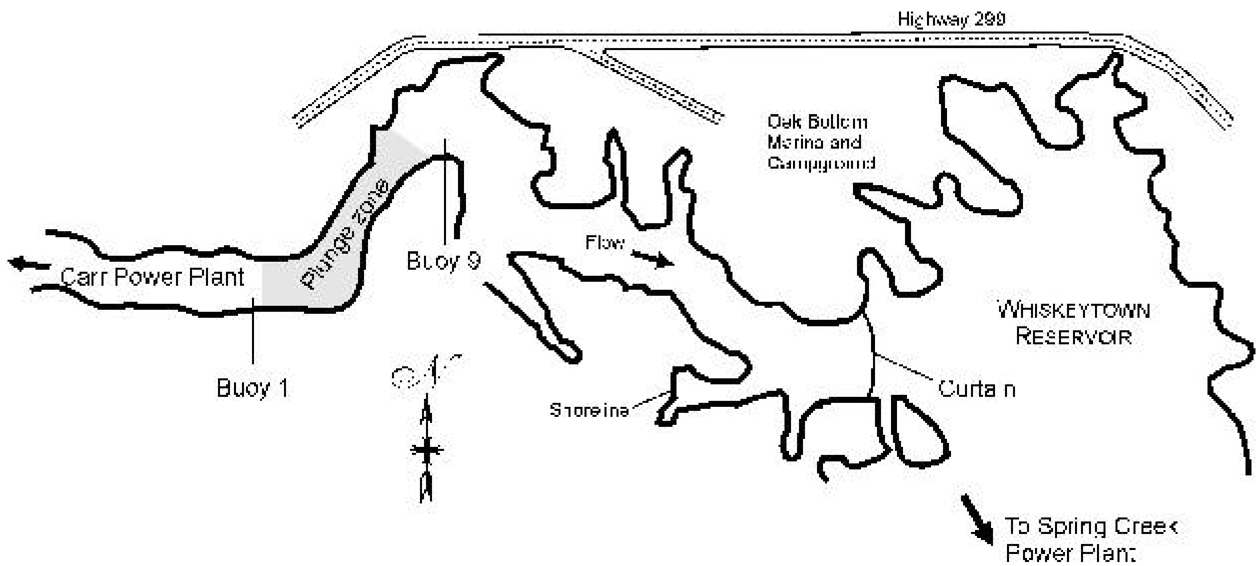

Figure 2. Location map of UC-Davis plunging inflow study site (not to scale).

4. Field Tests

The focus of this paper is a component of a research project studying the effects of plunging inflows on reservoir hydrodynamics and downstream release water temperatures. This project was conducted by the

University of California at Davis (UC-Davis) Civil and Environmental Engineering Department. Reclamation was requested by UC-Davis to provide technical assistance and velocity profiling using an ADCP. Velocity and temperature profiles were collected to quantify the hydraulic and thermal characteristics of the plunging inflows. The velocity data were collected using a RD Instruments 600 kHz ADCP. The boat-mounted ADCP was used to collect velocity profiles and measure 12 cross sectional areas upstream and downstream from the plunge zone. The discharge through Carr powerplant was held constant for each specific test. The temperature profiles were collected by UC-Davis using a conductivity-temperature-depth (CTD) probe. Additional information on the data collection and instrumentation is documented in Vermeyen (1996).

Two field tests were conducted during the week of June 9-15, 1996 and the second was conducted August 18-22, 1996. Two additional field tests were conducted during the summer of 1997. The first test was conducted during the week of August, 13, 1997 and the second was conducted September 3-4, 1997. This paper focuses on the data collected during the tests of June, 12-13, 1996 (table 1).

Field Test Date	**Carr Powerplant [m^3/s]**	**Spring Creek Powerplant [m^3/s]**
June 12, 1996	84.6	43.9 – 69.6
June 13, 1996	78.7	56.6
August 20, 1996	82.9	112.9
August 13, 1997	36.8	36.4 – 90.6
September 3,1997	48.7	48.7
September 4,1997	80.7	80.7

Table 1. Powerplant operations data for Whiskeytown Reservoir.

5. Sampling Sites

Sampling sites were established by UC-Davis researchers on both sides of the plunge zone. The sites were marked with buoys and positioned to mark the plunge zone. The furthermost upstream buoy was numbered one and the downstream buoy was numbered nine. A GPS (global positioning system) receiver was used to locate each of the profiling stations and to calculate distances between stations (table 2). ADCP transects were collected at the buoy locations to survey the site and to determine the channel's cross sectional area at each buoy. ADCP transects were also used to measure the velocity fields across the channel.

Buoy No.	Dist. from Carr PP (m)
1	1719.1
2	1836.4
3	1924.1
3.5	1971.3
4	2026.7
4.5	2057.9
5	2116.4
5.5	2168.5
6	2222.6
7	2323.6
8	2438.0
9	2575.0

Table 2. Distances from Carr Powerplant to the data buoys.

6. Results from the June 12 and 13, 1996 Field Tests

For the June 12 test, both the velocity and temperature profiles showed that the plunge zone was located between buoys 5.5 and 6.5 (figure 3-left panel). Variations in velocity and temperature at the other buoys showed the influence of the channel bends which created a sinuous plunge zone. The irregularity and unsteadiness of the plunge zone made it difficult to select sampling locations which were representative of the density current centerline.

For the June 13 test, both the velocity and temperature profiles showed that the plunge zone was located between buoys 3 and 4 which was about 300 meters upstream from the June 12 tests (figure3-right panel). The shift in the plunge zone location was most likely attributed to a reduced inflow (table 1). However, it may have been generated by a difference in the inflow temperature which fluctuates throughout the day. Previous studies reported that water diverted from Lewiston Reservoir has a diurnal fluctuation in temperature (Vermeyen 1997).

7. Summary

The described field tests were successful in measuring the hydrodynamics and mixing processes associated with a plunging inflow in Whiskeytown Reservoir. The boat -mounted ADCP was used to collect velocity profiles and to measure 12 cross sectional areas upstream and downstream from the plunge zone.

Visual and physical measurements revealed that it was very difficult to locate the plunge zone in this reservoir because of its sinuous bathymetry. Many times the plunge zone would be moving while collecting ADCP profiles. The unsteady plunge zone may have been generated by changing inflow temperatures or flowrates. Furthermore, interfacial shear mixing removes warm surface water which is not readily replaced, resulting in a gradual change in reservoir stratification.

The results from the field tests were compared with those computed using a numerical model developed to simulate density flows in stratified lakes (Knoblauch and Simões, 2000). This model uses a simplified representation of a single-branched reservoir and is capable of simulating a number of different phenomena, including the location of the plunge point. Additional information on the model is documented in Simões (1999).

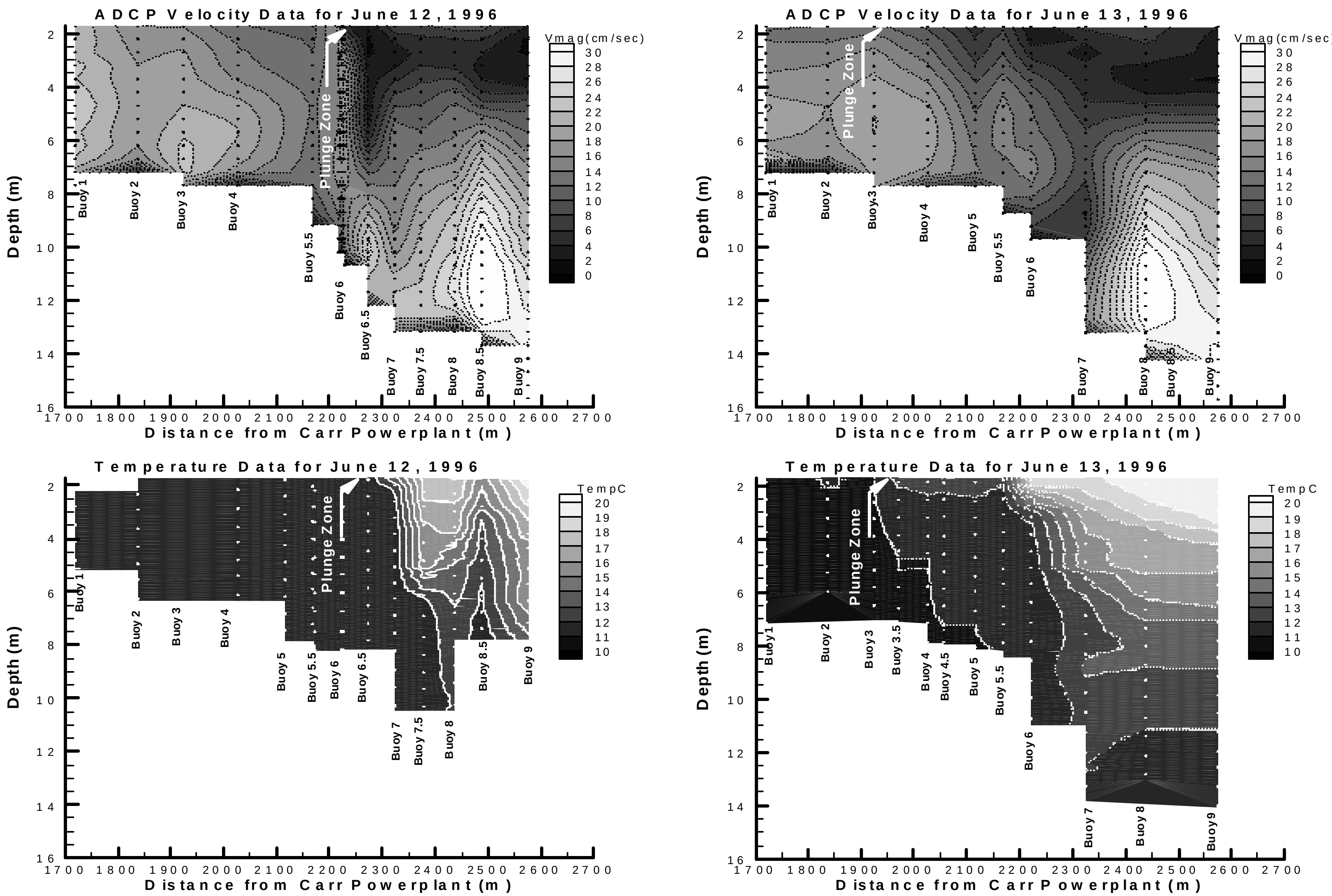

Figure 3. Plots of isovels (top) and isotherms collected in the plunge zone for field tests on June 12 (left panel) and June 13, 1996 (right panel). The white dots indicate locations of data collection.

8. References

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