Minnesota District
Quarterly Project Progress Report
Period ending December 31, 2007

January 3, 2007

<u>Project Name:</u> Determination of tributary inflows and in stream flow in the Mississippi River during base flow conditions, between Little Falls and Minneapolis, Minnesota

<u>Project Number:</u> MN 00115; 8607-00115

<u>Begin Date:</u> Sept. 2003 <u>End Date</u>: Sept. 2007 <u>Revision Date:</u> September 2, 2004*

<u>Project Chief:</u> J.D. Fallon <u>Cooperators:</u> City of St Cloud, Minnesota

Objectives

The objective of this project is to quantify tributary inflows and instream flows in the Mississippi River between Little Falls and Minneapolis, Minnesota*, a source-water protection area.

Data would be used to identify river reaches with ground-water discharge or recharge that could affect, or be affected by, contaminant spills. Specifically, (1) identify reaches of the Mississippi River that may be gaining discharge from or losing discharge to ground water, (2) determine the areas of greatest ground-water discharge, and (3) determine if ground-water discharge to the river is a significant portion of the river's flow during lower discharges in the Mississippi River.

*The scope was reduced to a shorter pilot reach from Monticello to Anoka after further research and consultation with hydroelectric dam operators. The reduced reach intended to minimize the effects of hydroelectric plant operations on river flows, and maximize the chances for steady-state flow conditions throughout the study reach during fieldwork—a condition necessary to detect measurable differences in streamflow among measuring locations.

Progress and Significant Findings since Last Report

As drought conditions developed during the summer and fall, the Mississippi River was monitored for favorable study conditions. Staff consulted and coordinated with hydroelectric plant operators and other water users and regulators, and frequently revised personnel schedules to free staff needed for the short but intensive field work. Because the Mississippi River is regulated and changes to streamflow are made continually by many water users, substantial efforts were made to minimize the amount of time needed to conduct field work, thereby maximizing opportunity for success, while minimizing disruptions to industry. Field work was completed November 8 and 9, 2006. Additional time was spent in the office finalizing measurements, compiling information, and preparing figures for presentation.

Seepage runs to determine gaining and losing reaches on rivers this size are not frequently attempted due to the difficulty in meeting necessary conditions, including the level of accuracy needed for discharge measurements and the rarity of steady-state flow conditions occurring throughout a large drainage basin. These issues were hoped to be addressed with new hydro-acoustic technology to make discharge measurements more accurately and quickly, and with a timely drought. However, the Mississippi River is a regulated river, with many water users storing, discharging, and withdrawing streamflow at variable rates. Periods of steady-state flow conditions greater than a few hours are extremely rare. Even with considerable coordination and cooperation with these entities, it was difficult to align (1) naturally occurring low-flow conditions with (2) an adequate duration of steady-state flows from multiple streamflow regulators, (3) enough field staff to quickly make the streamflow measurements. While not impossible, meeting all of the conditions simultaneously has not been practical.

Details of the November 8 and 9 effort follow: November 8, ten measurements were made on the Mississippi River from Monticello to Ramsey, Minnesota at approximately 2-mile intervals (figure 1, map). Measured discharges ranged from 2,400 to 2,870 cubic feet per second (cfs), (table 1). Four tributaries with observed flow were measured and discharge from two wastewater treatment plants were included. Total tributary inflow to the reach was determined to be 337 cfs. Measuring conditions generally were good and river conditions at each measuring section were fairly stable. Five manual water-level readings taken at Dayton varied no more than 0.01 ft during 1020 to 1345 hours.

Table 1 contains a summary of measurements and calculations used to attempt to identify gaining or losing reaches. After accounting for tributary inflows (columns 4-6), differences in streamflow greater than five percent were observed between most measuring sections (table 1, column 8). Streamflow differences greater than five percent between measurements are desirable because 5 percent is considered to be the error associated with a discharge measurement made under good conditions. Consequently, differences greater than 5 percent might be attributed to actual changes in streamflow. Observed differences alternated between positive and negative. Under steady state conditions, these differences might be attributed to gaining or losing reaches; however that conclusion is unclear from these data, due to complicating factors.

A post-fieldwork analysis of continuous stream stage data from two gages (one not available at the time of field work) indicate changes in river storage may have affected measured differences in streamflow. Travel times of changes in flow were estimated to determine when to conduct field work. A range of travel times was determined. Figure 2 shows provisional streamflow hydrographs during the study period at 2 gaging stations upstream of the study reach: (1) the USGS gage at the Mississippi River at St Cloud, and (2) the gage operated by Excel Energy at their power plant four miles upstream of Monticello, where the beginning of the study reach is located. (Data from the Monticello power plant were not available in real time). Analysis of these and other hydrographs indicate that, at a range of flows from 2,000 to 2,800 cfs, changes in flow measured at St Cloud take about 12 hours to reach the Monticello power plant 26 miles downstream. At these flows then, the travel time of a "floodwave" or flow disturbance would propagate or move downstream at a rate of about 2.2 miles per hour (mph) or 3.2 feet per second (ft/sec). A time of travel analysis done by the U.S. Army Corps of Engineers in 2004 estimated slower rates of about 0.6 mph, but this focused on particle movement, which can lag behind stage/discharge waves. A post analysis of discharge measurement data from this pilot study found the average of mean velocities from all mainstem measurements made in the study reach was about 1.4 ft/sec or 1 mile/hr (figure 3 shows cross section data from Mississippi River measurements). This value may be biased low for the entire reach because measurements were made in relatively slow moving sections of the river.

To assure that the entire range of travel-time estimates (0.6 – 2.2 mph) were covered in routing steady state flow conditions through the study reach would mean that water users would need to hold these conditions longer than practical (13 to 96 hours). Consequently, we used a middle value of 1.4 mph as a guideline for predicting when steady-state flow conditions existed in the study reach.

The uncertain travel times of flow disturbances may have affected measurements. Figure 2 indicates a significant flow disturbance occurred at the St Cloud gage November 5-6. The peak occurred November 6 at 1100 hrs and stabilized by November 7 at 0100 hrs. Based on a travel time of 1.4 mph (2 ft/sec), this peak would have arrived at measuring site number 1 in Monticello on November 7 at 0600 hrs and traveled through the study reach before field work began. The stable flows observed at the St Cloud gage November 7 at 0100 hrs would have arrived at the upstream end of the study reach by November 7 around 1700 hrs, traveled to the vicinity of reaches 8 and 9 when field measurements began (November 8 at 0900 hrs) and been at reach 10 by November 8 at 1400 hrs. Thus field work should not have been affected by this disturbance.

However, using the slower Corps of Engineers travel-time estimates (0.6 mph) to route the November 6 flow disturbance from the St Cloud gage would locate it further upstream. At the start of field work November 8, the peak would have been located just upstream of measuring site 1 in Monticello. The stable period observed November 7 at 0100 hrs at St Cloud would have been only about halfway from St Cloud to Monticello—not yet to the study reach. In the lower half of the study reach would have been the trough observed November 5 at the St Cloud.

If further research is desired, other methods or technologies may be needed to address the issue. These could include sampling shorter reaches to better control conditions, installing continuous stage-monitoring devices at each measurement section to better track changes in river conditions, or using mini-piezometers in stream-beds to verify head gradients between ground and surface water in the areas of interest. Such endeavors are beyond the scope of the current agreement.

Plans for Next Reporting Period

Update cooperator. Prepare measurement data for publication in 2007 Annual Data Report.

Other Activities

None.

Status of reports:

The original, full agreement called stated data will be (1) published in the Annual Report of the Minnesota District, U.S. Geological Survey, (2) posted on the internet as part of the USGS water-information system, NWIS web, and (3) published in an short interpretative report. This report will specify segments of the river that are gaining or losing reaches. River cross section and velocity profiles from ADCP measurements will be published.

Items 1-2 will be fulfilled: streamflow measurements will be published as Miscellaneous Measurements in the Water Resources Data, Minnesota, Water Year 2007 annual data report. This report will be available on-line at http://pubs.usgs.gov/wdr/.

Item 3 is beyond the revised scope of the pilot study. However, a summary of measuring locations, conditions, and results are included in this quarterly progress report.

Table 1. Locations and results of Mississippi River Seepage Study - Monticello to Anoka, November 8 and 9, 2006
PROVISIONAL DATA, SUBJECT TO CHANGE--DO NOT CITE

(1) Location	(2) Main-stem Measur-ing Sections	(3) Mea-sured Dis-charge (cfs)	(4) Tribu-tary Dis-charge (cfs)	(5) Cumu-lative Tribu-tary Dis-charge (cfs)	(6) Mississippi River Flow, Adjusted for Tributaries (cfs)	(7) Difference in Mississippi River Discharge between Measuring Sections (cfs)	(8) Difference in Mississippi River Discharge between Measuring Sections (percent)	(9) Cumu-lative gains or losses (cfs)
Mississippi River above WWTP in Monticello	1	2630			2630	--	--	--
Big Lake WWTP			2.0	--				
Monticello WWTP			2.0	4.0				
Mississippi River at Harding Ave in Monticello	2	2480		4.0	2480	-150	-6.0	-150
Mississippi River at Jalgar Ave in Otsego	3	2700		4.0	2700	220	8.1	70
Mississippi River at 101 St in Otsego	4	2400		4.0	2400	-300	-12.5	-230
Mississippi River above Mason Ave in Otsego	5	2500		4.0	2500	100	4.0	-130
Otsego Creek at Co. Rd. 39 in Otsego			0.76	4.9				
Mississippi River at Otsego City Park in Otsego	6	2720*		4.9	2720	220	8.1	90
Elk River at Mississippi Rd. in Elk River			141	146				
Mississippi River at County 42 in Otsego	7	2760*		146	2610	-110	-4.2	-20
Elk River WWTP in Elk River			1.6	148				
Mississippi River above St. Croix Drive in Otsego	8	2720		148	2570	-40	-1.6	-60
Mississippi River above Crow River in Otsego	9	2860		148	2710	140	5.2	80
*Crow River above mouth at Dayton (adj. Nov. 8th)			*189	337				
Mississippi River at Armstrong Blvd. in Ramsey	10	2870		337	2530	-180	-7.1	-100
Crow River above mouth at Dayton			182					

Column Definitions
(1) Location -- The location of discharge measurement. Locations of tributaries are indented.
(2) Section -- Mississippi River channel measuring section numbered from upstream to downstream, correspond to numbered locations on map.
(3) Discharge -- Discharge measured on the Mississippi River by ADCP or ADVM
(4) Tributary Discharge -- Measured or furnished discharge of the tributary or other source.
(5) Cumulative Tributary Discharge- running total of inflows
(6) Mississippi River Flow, Adjusted for Tributaries -- Columns (3) + (5)
(7) Difference in Mississippi River Section Discharges -- The difference between this discharge measurement and the one upstream of it - adjusted for inflows.
(8). Percent discharge -- The difference in Mississippi River discharges as a percent of the discharge. The error of the discharge measurements is less than 5 percent. Percent discharges less than 5 percent are within the error of the discharge.*Discharges rated less than good have margin of error of up to 8 percent.
(9) Sum of gains or losses-- The sum of the gains and losses.

* Adjusted upwards from measured flow on Nov. 9th and 4% loss in flow per day.

Figure 1. Map showing locations of study reach, streamflow measurements, and furnished discharge data.

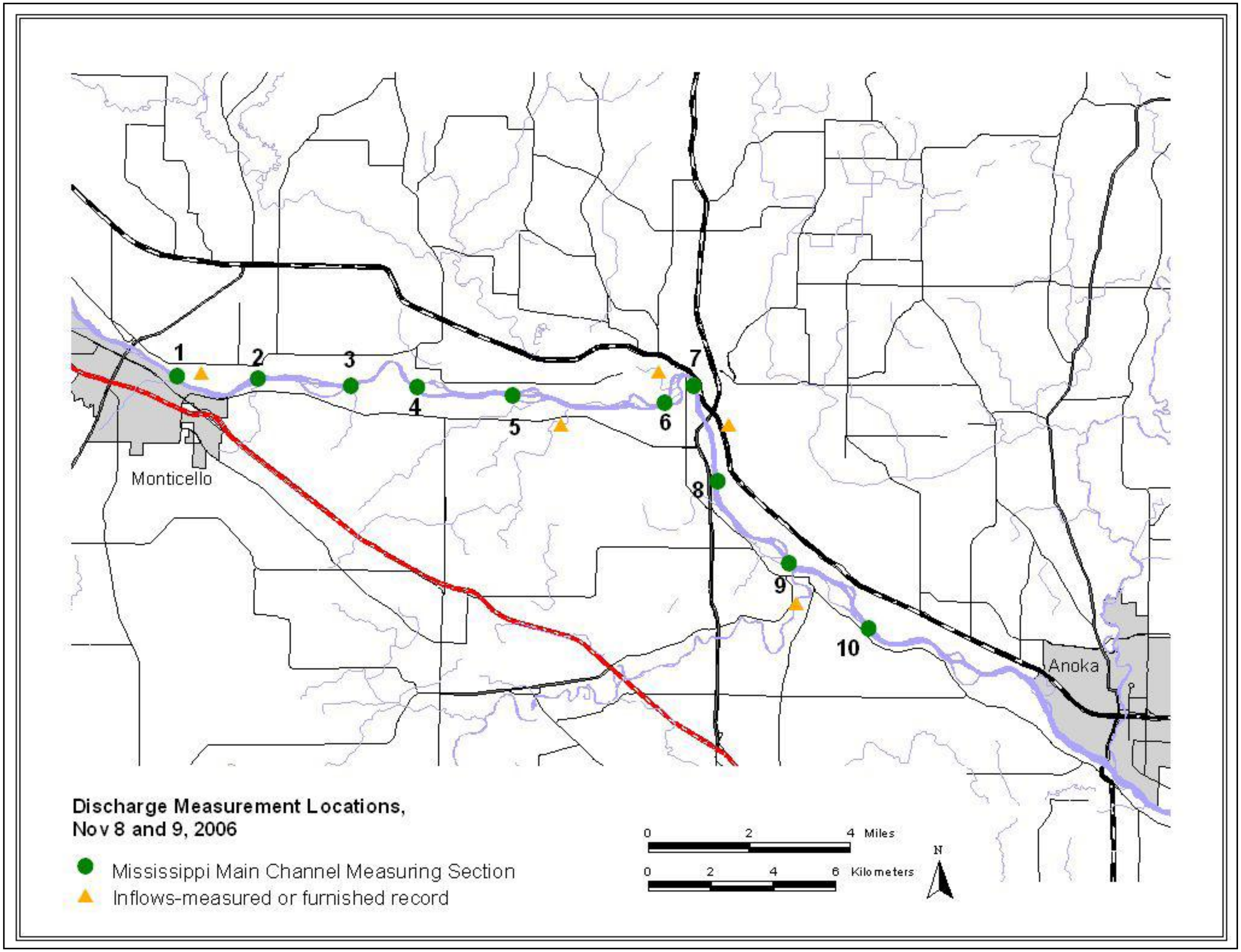
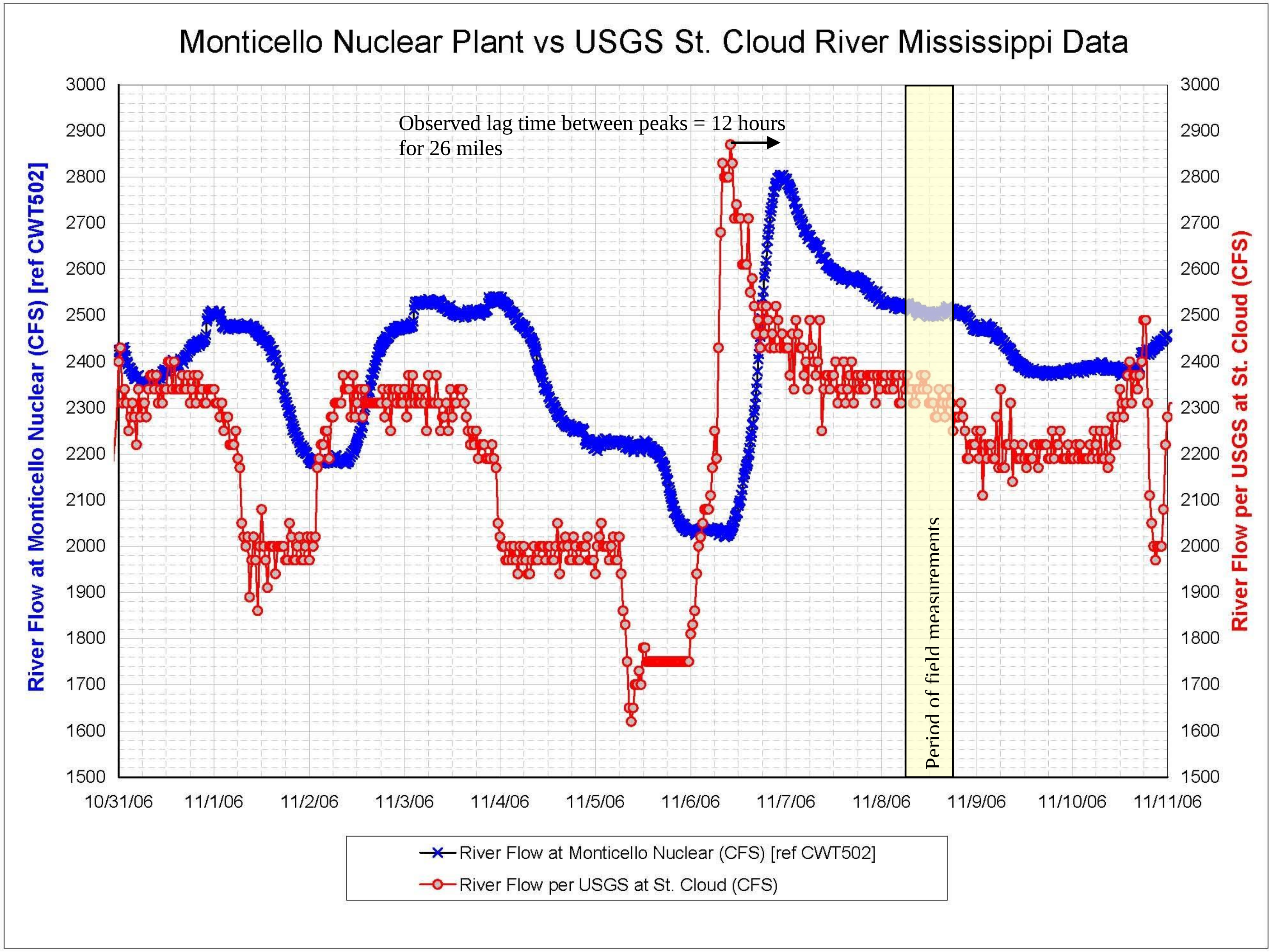


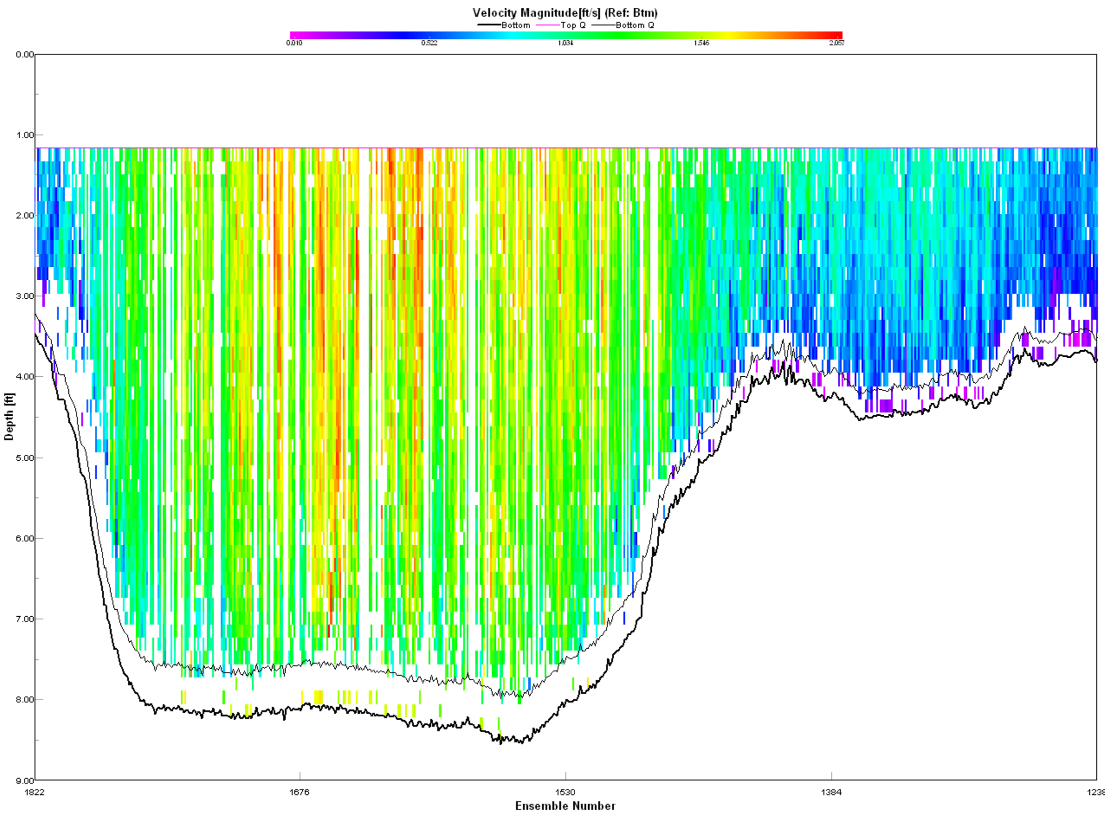
Figure 2. Provisional streamflow hydrographs from gages on Mississippi River upstream of study reach, at St Cloud and above Monticello, Minnesota. Graph provided by Excel Energy.



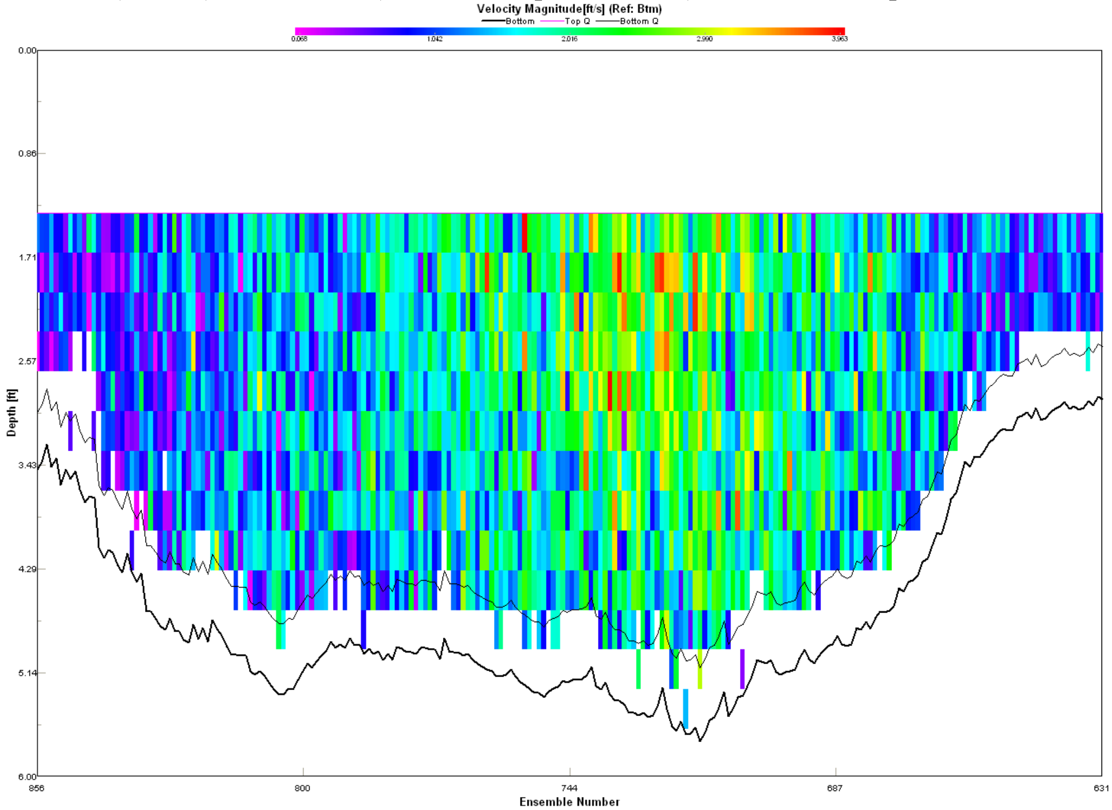
j:\engr\plant_data\system_data\cwt\EXCEL-Monticello vs USGS St Cloud thru 11-06; Flow

Figure 3. Cross-sections of stream velocities obtained during measurements made on the Mississippi River by acoustic Doppler current profiler (ADCP) using a boat, or acoustic Doppler velocity meter (ADVM) while wading, November 8, 2006.

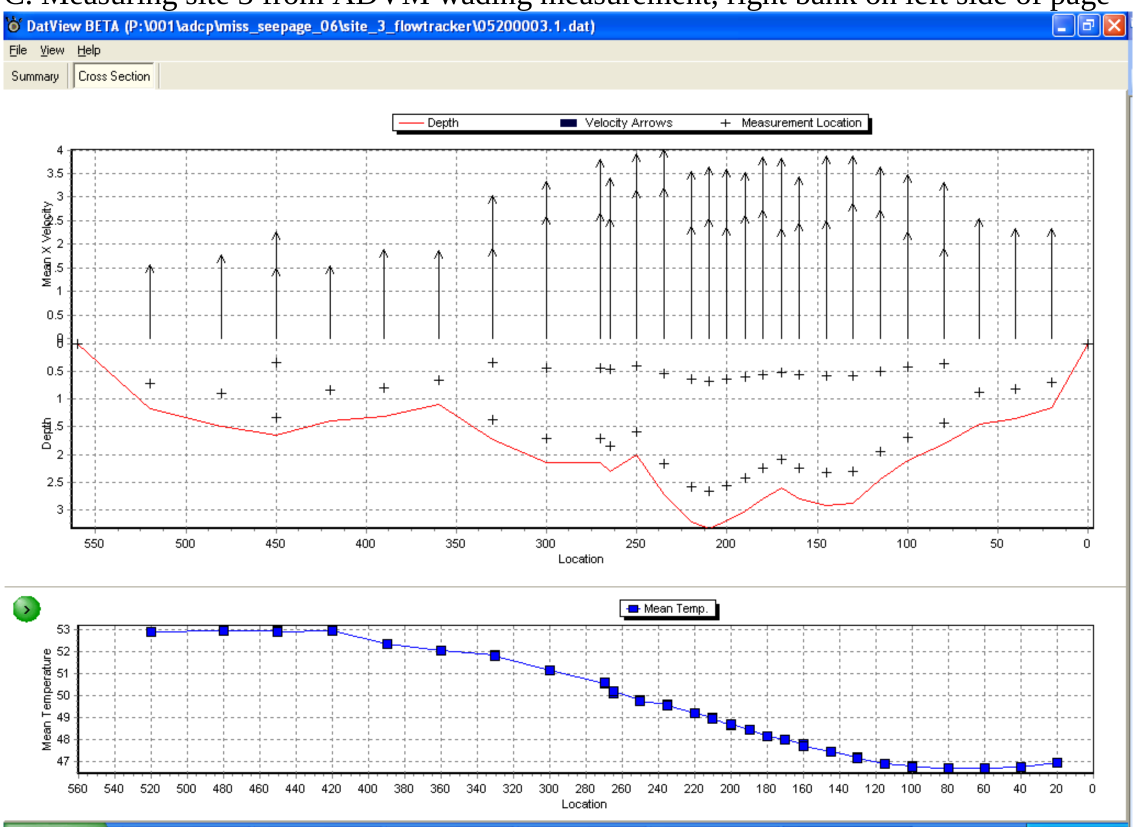
A. Measuring site 1 from ADCP, right bank on left side of page.



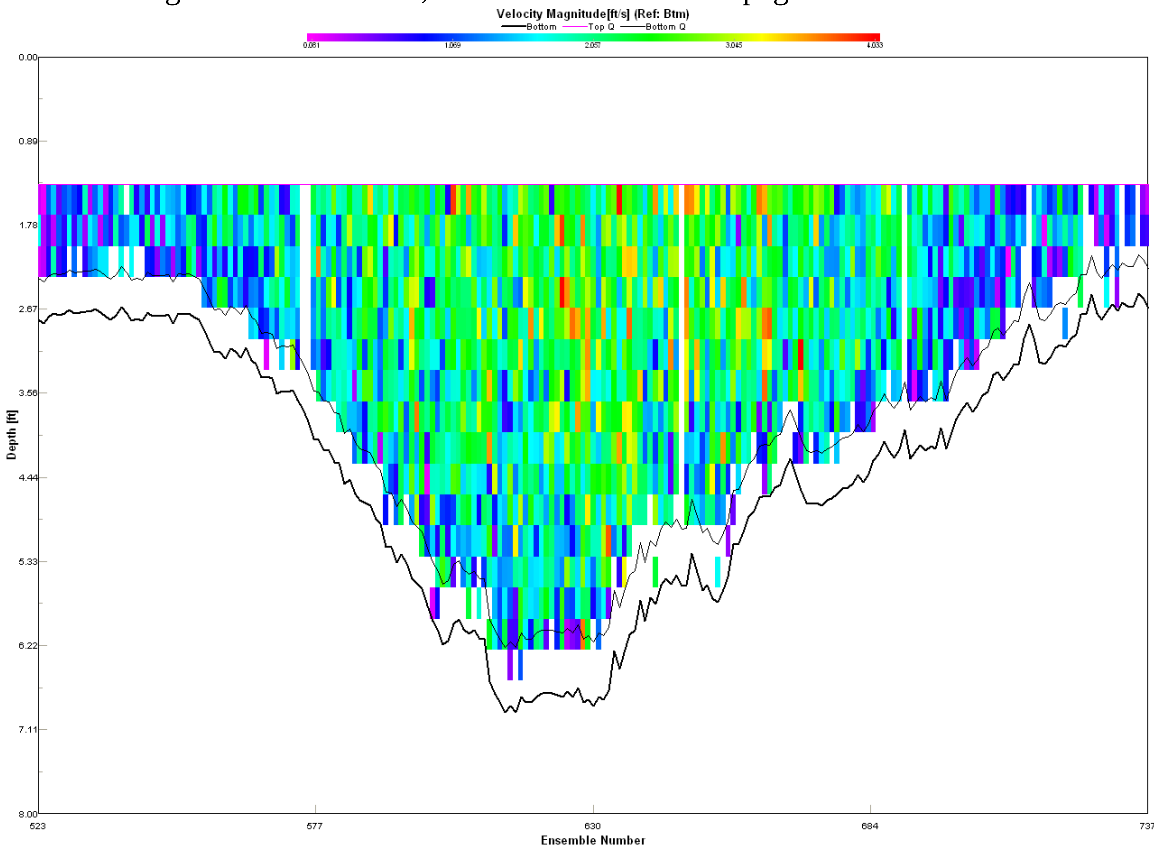
B. Measuring site 2 from ADCP, right bank on left side of page. This cross-section was partially measured by ADVM (waded) and ADCP (boat for deeper sections). The screen capture is from the ADCP.



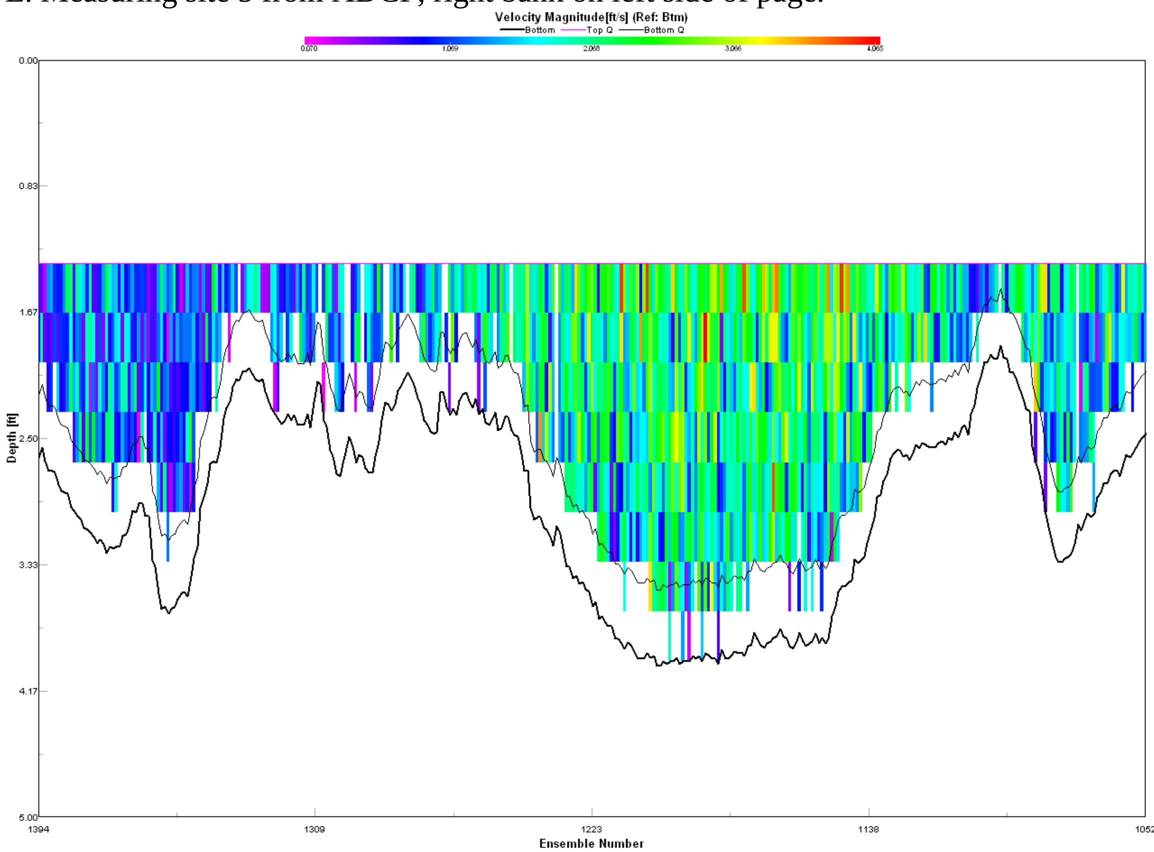
C. Measuring site 3 from ADVM wading measurement, right bank on left side of page



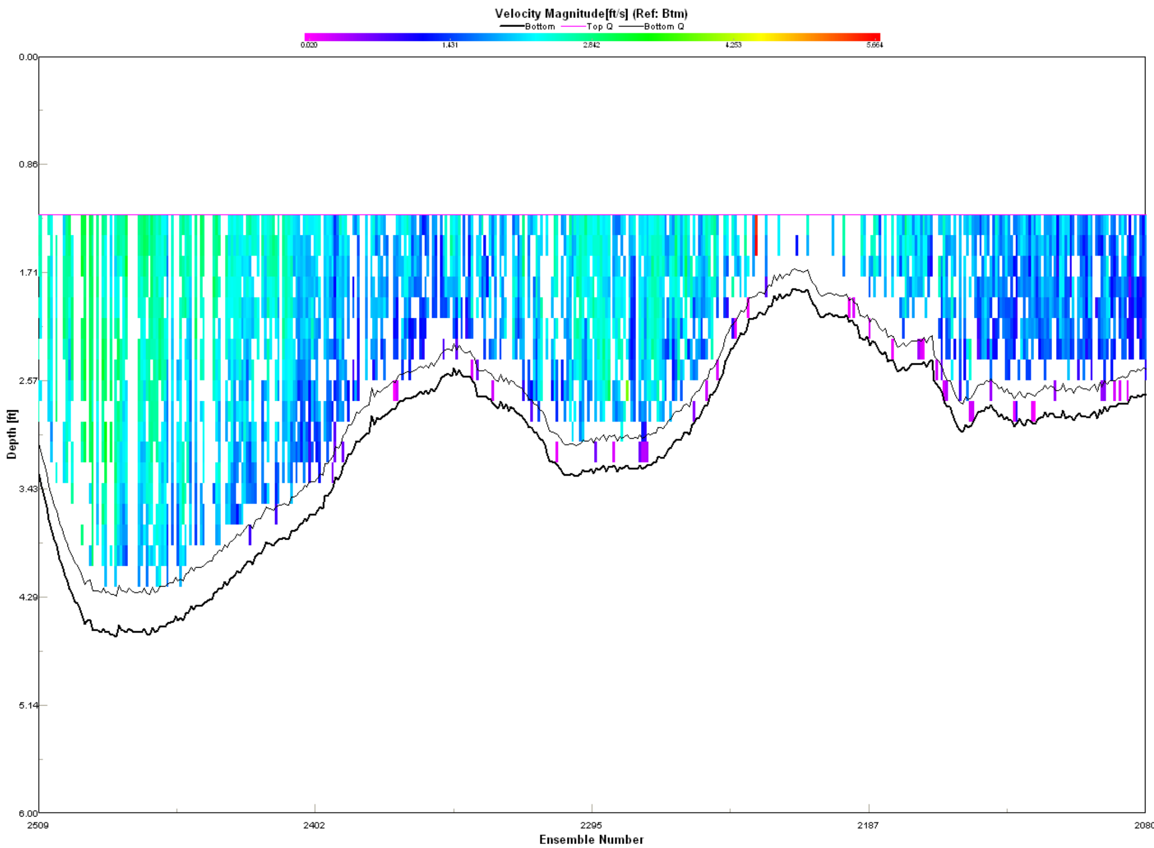
D. Measuring site 4 from ADCP, left bank on left side of page.



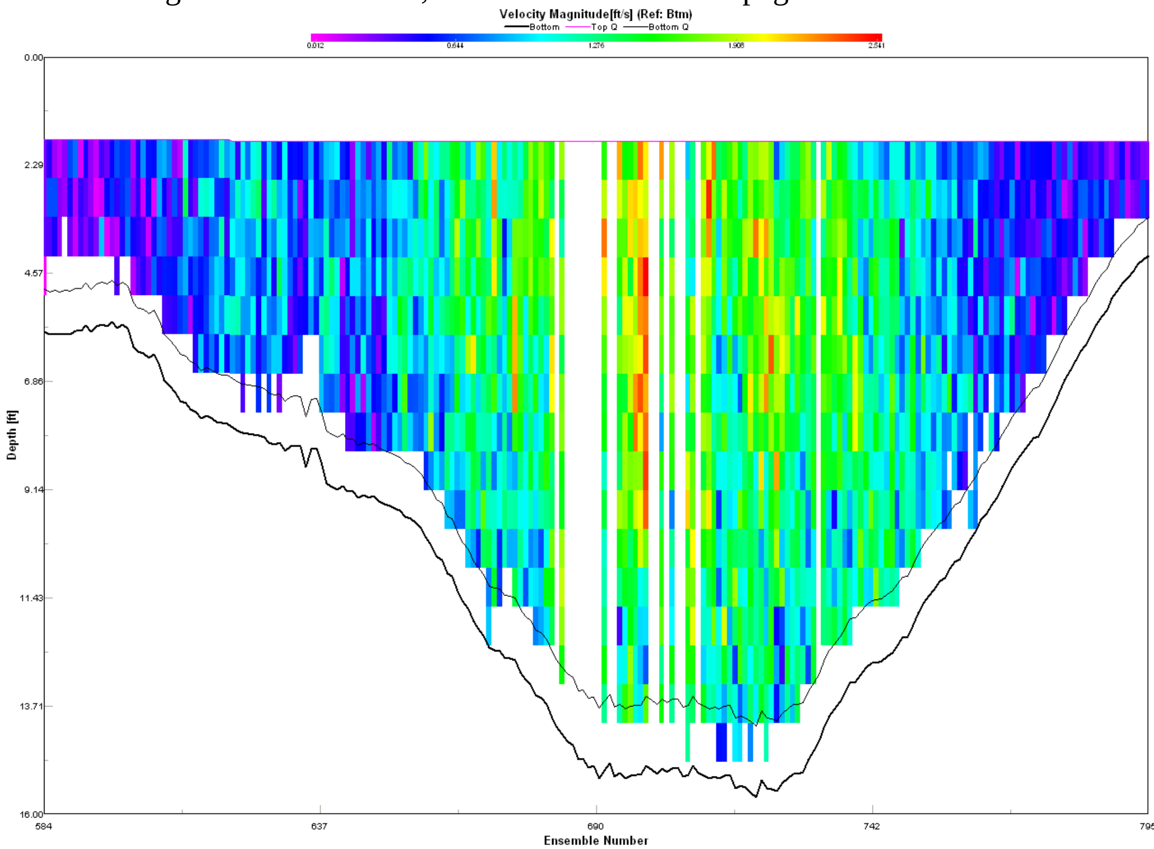
E. Measuring site 5 from ADCP, right bank on left side of page.



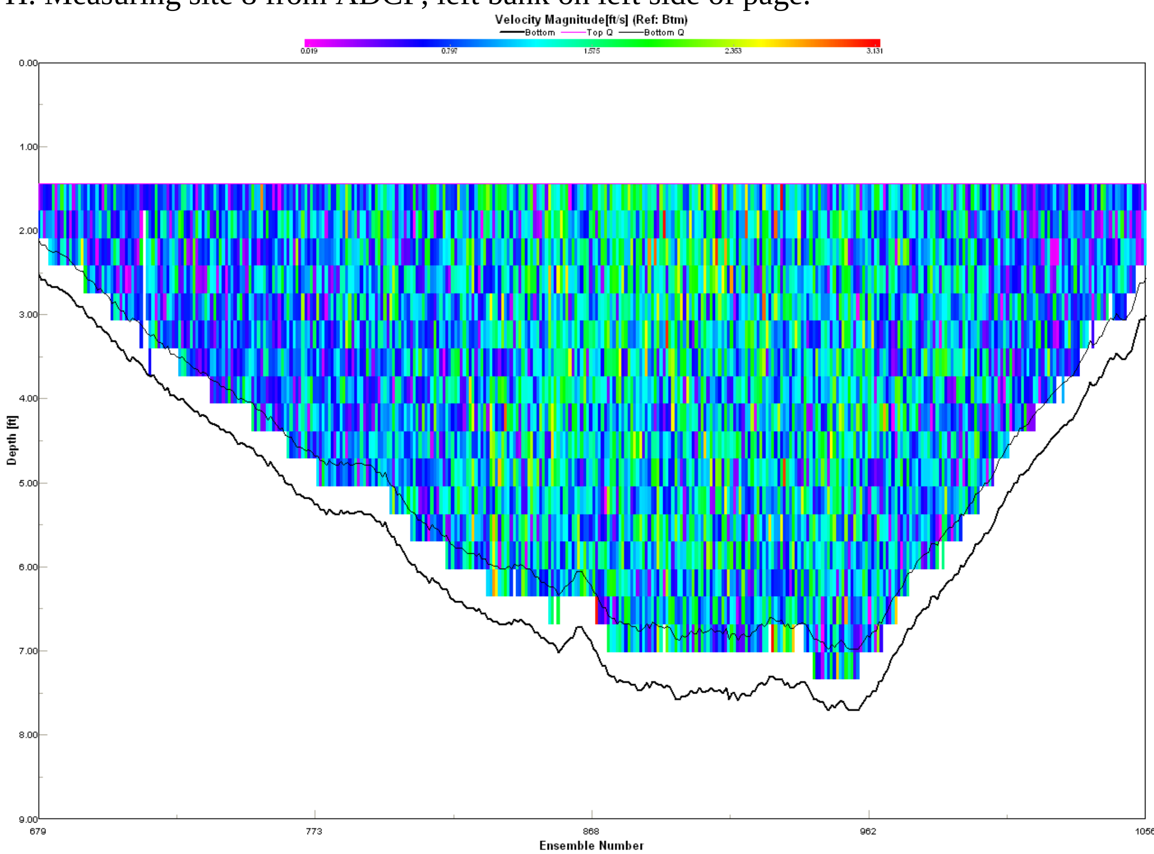
F. Measuring site 6 from ADCP, right bank on left side of page.



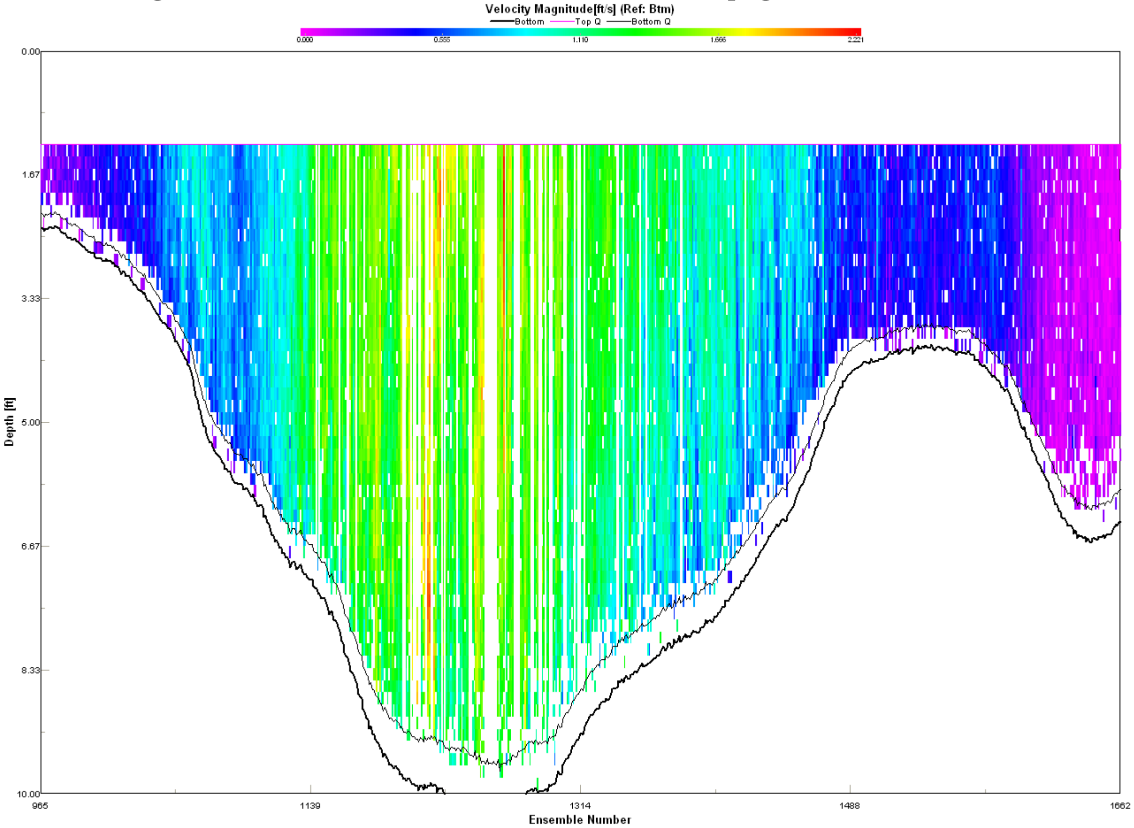
G. Measuring site 7 from ADCP, left bank on left side of page.



H. Measuring site 8 from ADCP, left bank on left side of page.



I. Measuring site 9 from ADCP, left bank on left side of page.



J. Measuring site 10 from ADCP, left bank on left side of page