# ICPRB Potomac River Level Monitoring
# Summer 2005 Pilot Study Report

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## Introduction

Several river level monitors were deployed along the Potomac River by ICPRB during the summer of 2005 in a full-scale pilot deployment (Figure 1). The monitors are used to provide an advance prediction of river flows in order to monitor and improve the efficiency of water supply releases. These monitors were located at Edwards Ferry, the mouth of Seneca Creek, and at Great Falls (Figure 2). In addition, Figure 2 shows the locations of nearby USGS gages and a potential future site for further monitoring.

This report provides a summary of the equipment used and the data collected. It also presents preliminary data analysis, an overview of the lessons learned, and provides conclusions/recommendations.

The monitors are funded by the three Washington metropolitan water suppliers including the Washington Aqueduct of the U.S. Army Corps of Engineers, the Washington Suburban Sanitary Commission, and Fairfax Water. The information obatined by the monitors is interpreted using data collected by gages maintained by the United States Geological Survey. Without the USGS gages, the river level measurements would be of little value for drought operations.


**Figure 1: Inside the river level monitor at Edwards Ferry**

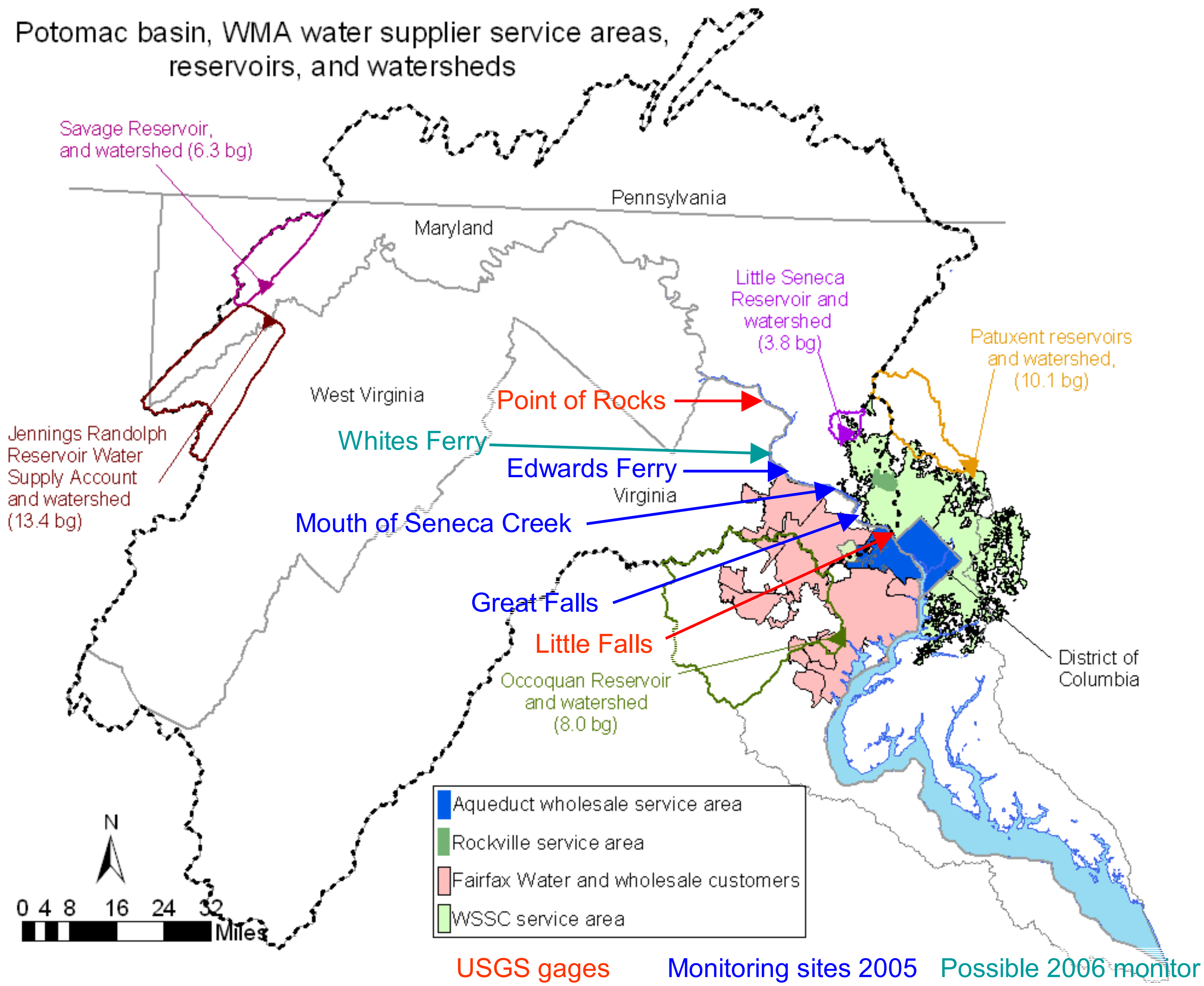



**Figure 2: Potomac watershed and pilot monitoring sites in 2005, nearby USGS gages, and possible additional site monitoring location for 2006**

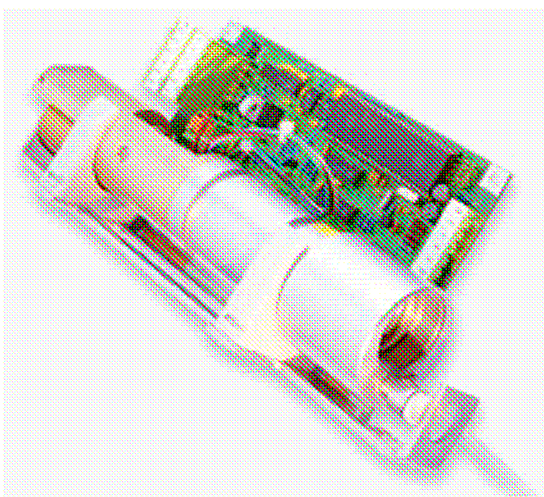
## Equipment

The monitoring system has several components, including:

- Stage measurement device
- Software
- Communications system
- Enclosure
- Power source

### Stage Measurement Device

The Nimbus Bubbler Water Level Sensor manufactured by Ott (Nimbus bubbler), pictured below, was used to monitor river level. The Nimbus bubbler was purchased through Hach Environmental, which provided technical support and helped in initial gage deployment.



The Nimbus bubbler is designed for continuous monitoring of groundwater and surface water levels. The Nimbus bubbler measures the force required to push air through a measuring tube into the water to be measured. The pressure in the measuring tube is directly proportional to the water column above tube end. The Nimbus subtracts barometric air pressure from the pressure at the end of the tube to calculate the height of the water level above the tube end. The pressure required is used to determine water elevation, and is automatically corrected for changes in atmospheric pressure. The pump used to blow air is driven by an internal, maintenance-free compressor. Measured values (up to 11,200 samples) can be stored onto an internal memory card. Measured values can be recorded in intervals of between 5 minutes to 24 hours. A 12-volt automobile or marine battery is the power supply, which can be augmented by solar power.

### Software

The Nimbus bubbler monitors the water level, and iChart Software, Version 5.04.012, created by NexSens Technology ™ is used to:

- download stage data
- generate reports automatically
- post data to the internet automatically

The software also allows the instrument to automatically send an alarm in the form of an email message and pager signal when the water level rises above or drops below a specified threshold.

### Communications system

The Raven modem, manufactured and sold by Airlink Communications, Inc. is used to transmit the river level data to the office. The Raven is a wireless data platform designed to enable real-time, two-way communications with remote instrumentation using Code-Division Multiple Access (CDMA).

CDMA is a digital cellular technology that uses spread-spectrum techniques. The signal is sent over numerous frequencies, which allows numerous signals to occupy a single transmission channel and optimizes the use of available bandwidth. Unlike competing systems, CDMA does not assign a specific frequency to each user. Instead, every channel uses the full available spectrum. Individual conversations are encoded with a pseudo-random digital sequence. The frequency of the transmitted signal is made to vary according to a defined code or pattern, so it can be intercepted only by a receiver whose frequency response is programmed with the same code. There are trillions of possible frequency-sequencing codes. CDMA provides better capacity for voice and data communications than other commercial mobile technologies, allowing more subscribers to connect at any given time.

CDMA is a military technology first used during World War II by English allies to foil German attempts at jamming transmissions. The allies decided to transmit over several frequencies, instead of one, making it difficult for the Germans to pick up the complete signal. The technology is used in ultra-high-frequency (UHF) cellular telephone systems in the 800-MHz and 1.9-GHz bands.

The original CDMA standard, also known as CDMA One and still common in cellular telephones in the U.S., offers a transmission speed of up to 14.4 Kbps in its single channel form and up to 115 Kbps in an eight-channel form. CDMA2000 protocol, used by the Raven, delivers data many times faster. CDMA2000 is also known as IMT-CDMA Multi-Carrier or 1xRTT.

Raven Specifications

- 224 mW RF output (+23.5 dBm)
- Full duplex transceiver
- Dual-band support for both 800 MHz cellular and 1.9 GHz PCS bands
- CDMA authentication as specified in CDMA2000 1X
- Data rates up to 153.6 kbps (forward channel) and 76.8 kbps (reverse channel)

Power specifications:

- Input Current: 40 mA to 200 mA
- Typical Receive: 200 mA at 12V DC
- Typical Transmit: Approximately 200 mA at 12V DC
- Dormant connection [idle for 10-20 seconds]: 40 mA at 12 V DC

### Enclosure and power source

A standard car battery is used to power the gage, at a reserve power rating of 90 amp-hours. This size battery can power the gage for 55 days given a 15-minute sampling interval and a 15 minute interval for querying the modem.

The instrumentation is enclosed in a high-density plastic Pelican™ 1500 case, which is watertight and dustproof. The Pelican case is housed in a reinforced steel chest, model 32 JOBMASTER chest made by Knaack™ with the following dimensions: H: 13" W: 19" L: 32". Although this chest is heavy at 84 pounds, it has good handles for carrying into the field and has a well protected lock mechanism. The Pelican case was drilled to accommodate cables/wires, and sealed with silicone. Desiccant packs are exchanged periodically to control humidity within the box.

The Knaack enclosure is bolted to two pieces of 4” x 4” pressure-treated lumber. These are designed to be bolted to other pieces of 4” x 4” pressure-treated lumber which are in turn mounted to concrete walls or sunk into the ground and anchored with concrete. The Knaack enclosure itself is locked to a tree or guard railing as an additional security measure using readily available plastic coated steel cable.

## Field deployment notes

### Edwards Ferry

The Edwards Ferry monitor is located about 100 yards upstream of the boat ramp on the Maryland side of the river. It is about 75 feet away from the river on a secondary flood plain.

The monitor has an added level of protection from flooding, in that the gage is on a high point relative to the floodplain around it. The monitor's datum is the Edwards Ferry boat ramp. Looking towards the river, the datum is located at the top right corner edge of the highest part of the boat ramp. The elevation of the bottom of the Knaack ™ chest is at 111 feet relative to the boat ramp datum. The monitor is pictured above with ICPRB staff Cherie Schultz, in a view towards the river.

### Great Falls

The Great Falls monitor was located at the Aqueduct intake at Great Falls. The monitor was located on the lower platform. The datum was located on the platform on the highest part of the river-side railroad track stop, just outside the double doors of the intake structure on the upstream side.

### Mouth of Seneca Creek

The monitor was located about 200 yards downstream of the C&O Canal Aqueduct at the mouth of Seneca Creek on the Maryland side. The gage datum was located at a large tree root 5 yards downstream of the gage and marked with a hex-headed galvanized bolt. The elevation of the bottom of the Knaack ™ chest was at 101.8 feet relative to the datum, but this would change if a permanent gage housing structure is approved by the NPS.

### Field checklist

Not all items are necessary for each field trip, but staff found it useful to use a checklist prior to field work. These field lists are provided below.

**Surveying**

- Level, rod, tripod.
- Calculator, notebook, and pen.
- Hex headed wrench, bolt, if placing reference mark.
- Insect repellent.
- Sunscreen.
- Water, lunch.
- Cell phone for useful/emergency contact

**Gage box deployment or tubing placement**

- Shovel, mattock, digging bar, trowel, post-hole digger.
- Concrete (for permanent gages if permit approved), barrel for concrete mixing.
- Insect repellent.
- Sunscreen.
- Utility knife.
- Notebook, pen.
- Change of clothes, towel, swimsuit if placing tubing in river.
- Tivas, change of shoes.
- Waders.
- Battery carrier (frame part of backpack) and barrier.
- Cable ties.
- "Marine Goo" for waterproofing equipment box.
- Tubing and connectors.
- Fresh desiccant for inside equipment box.
- First aid kit.
- Water, lunch, cooler.
- Wire splicer/stripper.
- Hand drill/cordless drill/ drill bits.
- RX cable tool.
- Needle nose and general purpose plyers.
- Various RX cable connectors as required.
- Goggles if placing tubing.
- Pipe wrenches.
- Hack saw.
- Measuring tape.
- Spare batteries, camera.
- Cell phone for useful/emergency contact

## Data Collection 2005

An overview of the data collected compares the relative change in elevation at each gage (Figure 3). The Edwards Ferry gage had the largest fluctuation in river stage for a given flow rate, as the river is narrower at Edwards Ferry than at the other gage locations. The river width at Edwards Ferry is approximately 1,200 feet, so even small changes in flow rates during low flow periods are more likely to be measurable by the river level monitor. The Great Falls gage had the least variation for given changes in flow rate. This is a significant drawback to this gage. It is located at a wider part of the river (approximately 2,800 feet as measured across the broad crested weir, which is the effective river width at low flow), so small changes in flow rate may not result in measurable changes in river elevation.

Simulated data from the Edwards Ferry gage was extremely useful for operations during the 2005 drought exercise. We will continue to evaluate the utility of this gage for determining how much water to release from Little Seneca Reservoir. A release from Little Seneca Reservoir is approximately a 27 to 30 hour travel time to Little Falls during extreme low flows such as those warranting water supply releases (Kiang, Hagen, 2003) which is similar to the travel time from Edwards Ferrry gage to Little Falls during low flow conditions. A redundant gage is recommended at a location slightly upstream, at White's Ferry in case the Edwards Ferry gage is down during drought operations.

The monitor near Seneca Creek showed the timing of the arrival of the Little Seneca release in the Potomac, which would be important information to have for drought operations. This gage also can be used to provide another estimate of flow in the Potomac at Little Falls. This gage would be valuable for drought operations, both as a backup for predicting Little Falls flow and for monitoring the arrival of the Jennings Randolph and Little Seneca releases.

Great Falls data is available for only the early part of the summer, as there were problems with the data collected in the latter half of the summer and early fall. (Early problems included an inability to communicate with the gage using CDPD wireless technology. This problem was resolved by using a CDMA modem. A later problem was that after about July 12 there was either a leak in the tubing, or more likely, that the tubing was inadequately secured to the rebar anchor.) At low flows, it may be difficult to measure differences in elevation at the gage as noted above. The Great Falls gage had the least utility of the three gages in terms of drought operations, since it was too far downstream to be of much use for decision-making and showed little sensitivity to changes at low flows. It is recommended that this river level monitoring site be discontinued.

Note that the Edwards Ferry gage can be used to predict the magnitude of a high flow event, and could also potentially provide some utility in terms of flood warning (Figure 4). Warnings automatically can be sent to multiple email recipients in the event of high flow triggers. Downstream facilities potentially affected by floodwaters might include the water suppliers' Potomac intakes, as well as the National Park Service at Great Falls.

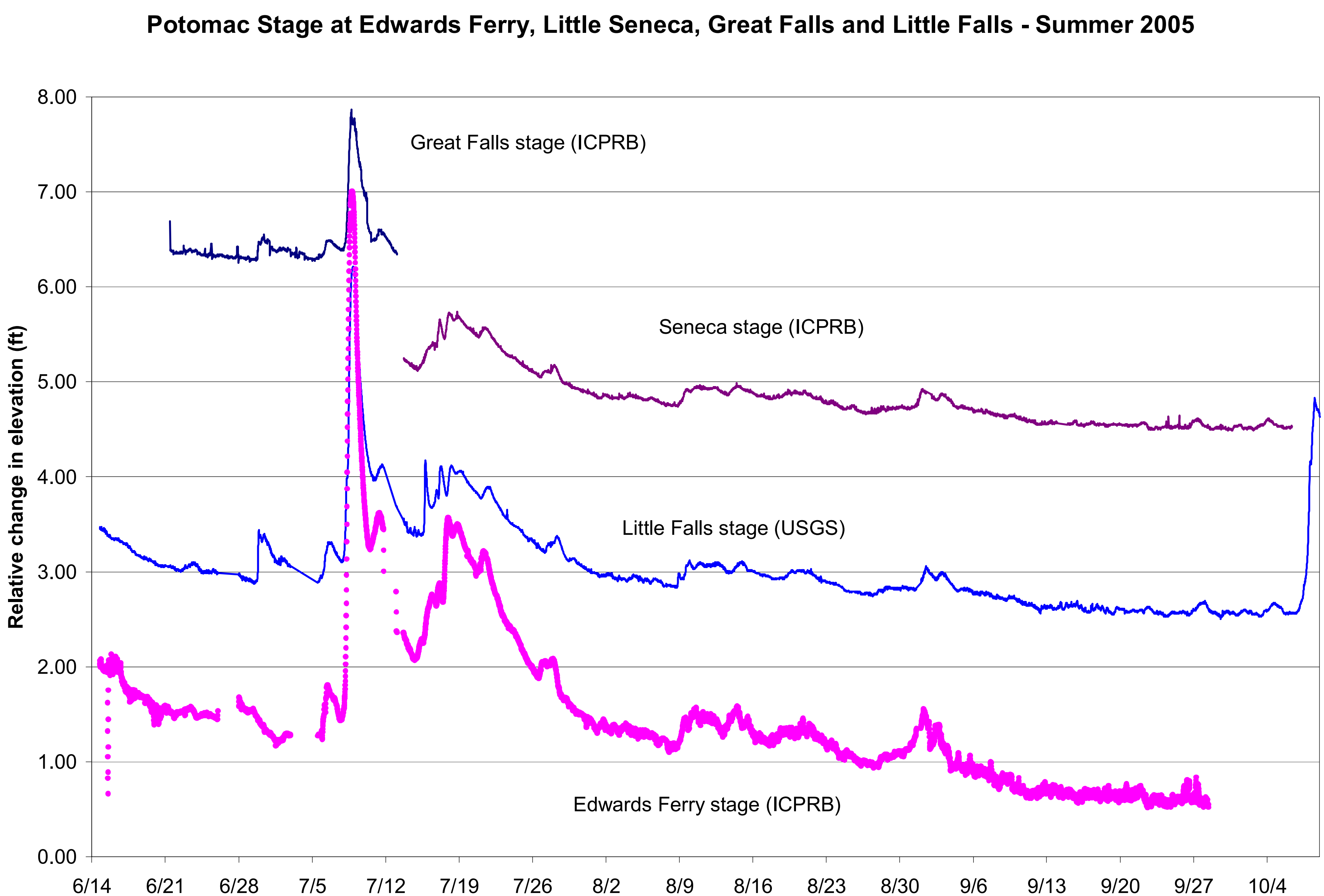



**Figure 3: Relative change in Potomac water elevation at Edwards Ferry, mouth of Seneca Creek, Great Falls, and Little Falls**

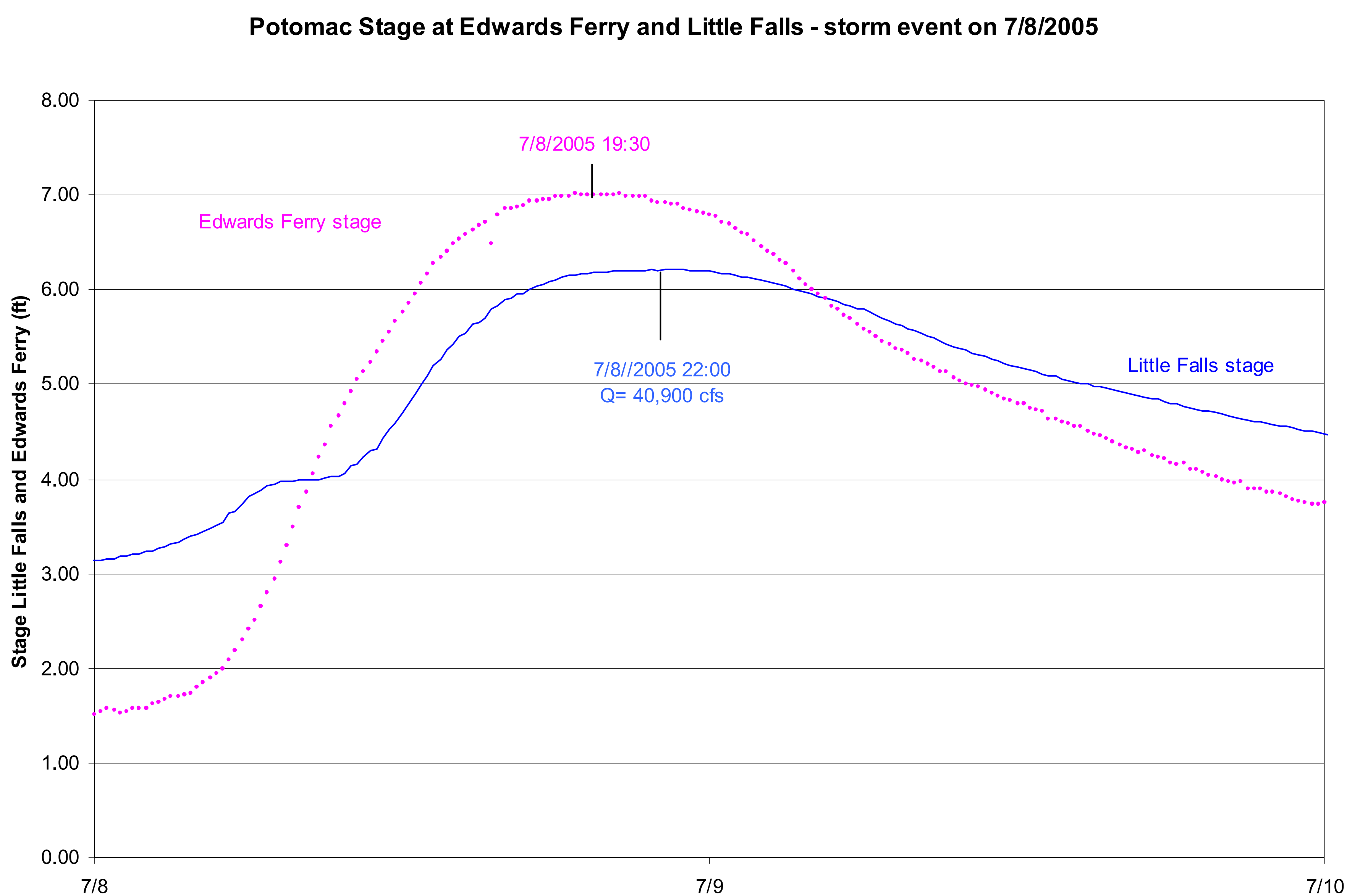



Figure 4: Potomac stage at Edwards Ferry and Little Falls, storm event 7/8/2005

## Data analysis

The data were analyzed to determine the travel time from Edwards Ferry to Little Falls, and to correlate Edwards Ferry data to adjusted flow at Little Falls. (Adjusted flow is the flow that would occur at Little Falls without water supply withdrawals).

### Travel time from Edwards Ferry to Little Falls

The Edwards Ferry river monitor can be used to predict flow at Little Falls. Travel time from Edwards Ferry to Little Falls varied considerably depending on background flow rates (Figure 5). Travel times are longer for lower flows. The data points in Figure 5 were developed by choosing well defined points on the hydrograph to determine an approximate travel time. Travel times ranged from approximately 2.5 to 25 hours for observed flow rates of 957 MGD to 26,800 MGD at Little Falls (adjusted).

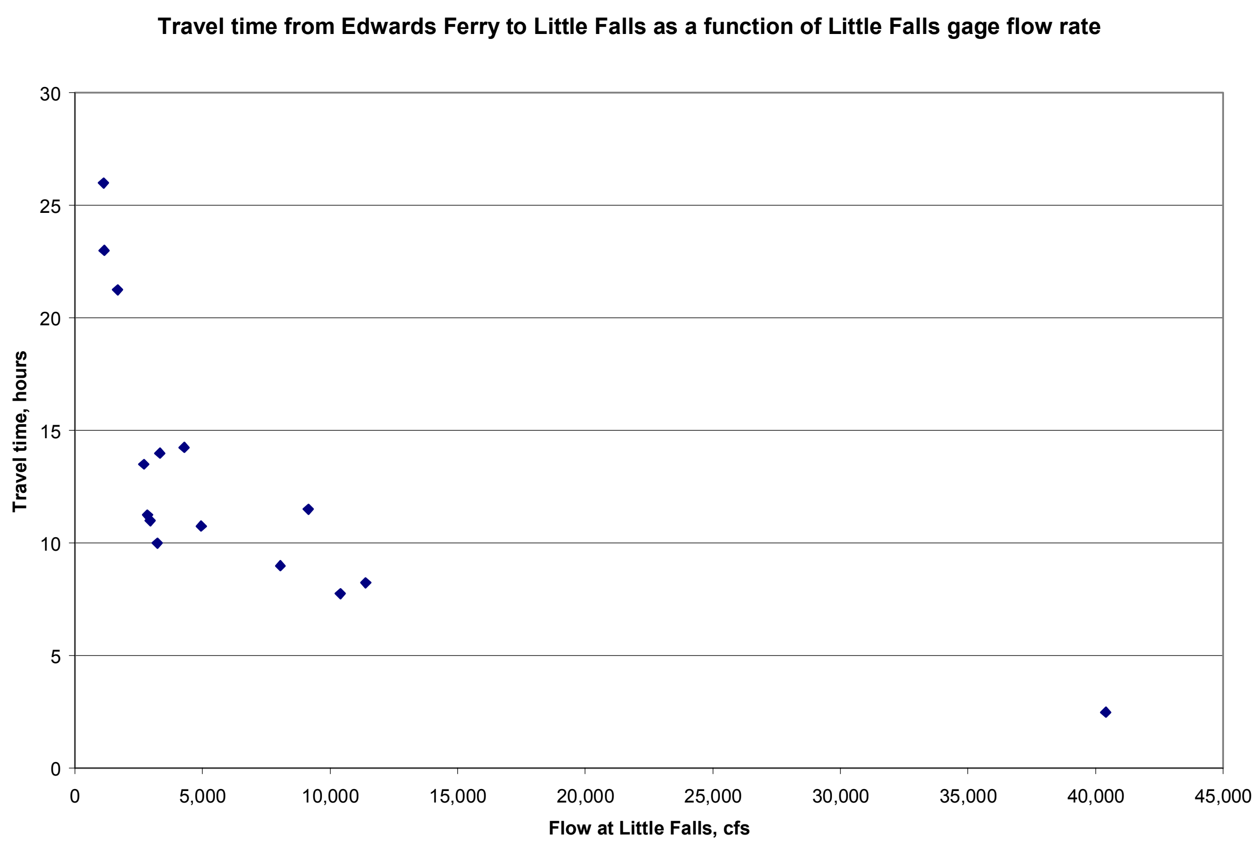



**Figure 5: Travel time from Edwards Ferry to Little Falls as a function of Little Falls gage flow**

### Estimating Little Falls flow using upstream river level monitors

The stage measured at Edwards Ferry can be used to estimate flow that would occur at Little Falls before water supply withdrawals, by correlating the stage measurements at Edwards Ferry with adjusted flow measurements at the nearby USGS gage at Little Falls. The first step was to adjust the daily flow at Little Falls to account for upstream water supply withdrawals. The water suppliers provided daily withdrawals to ICPRB so that an adjusted flow record could be determined. Edwards Ferry data was lagged using the travel time relationship established in Figure 5 in order to associate each data point at Edwards Ferry with an estimated adjusted flow rate based on Little Falls gage. These relationships are provided in Figure 6, Figure 7, and Table 1.

The relationship between stage and discharge is clear from Figure 6 and Figure 7. Table 1 should provide a good approximation of the stage flow relationship, as much data has been collected thereby providing a good estimate of the central tendency. Table 1 shows the standard deviation of the flow estimate, which averaged 117 MGD for the range of flows between 1,090 to 2,470 MGD. This is a relatively high standard deviation for flow management purposes. The table will be refined as more data is collected. Strategies to address the relatively high standard deviation in the data are discussed in more detail in the section of this report titled “Lessons Learned.”

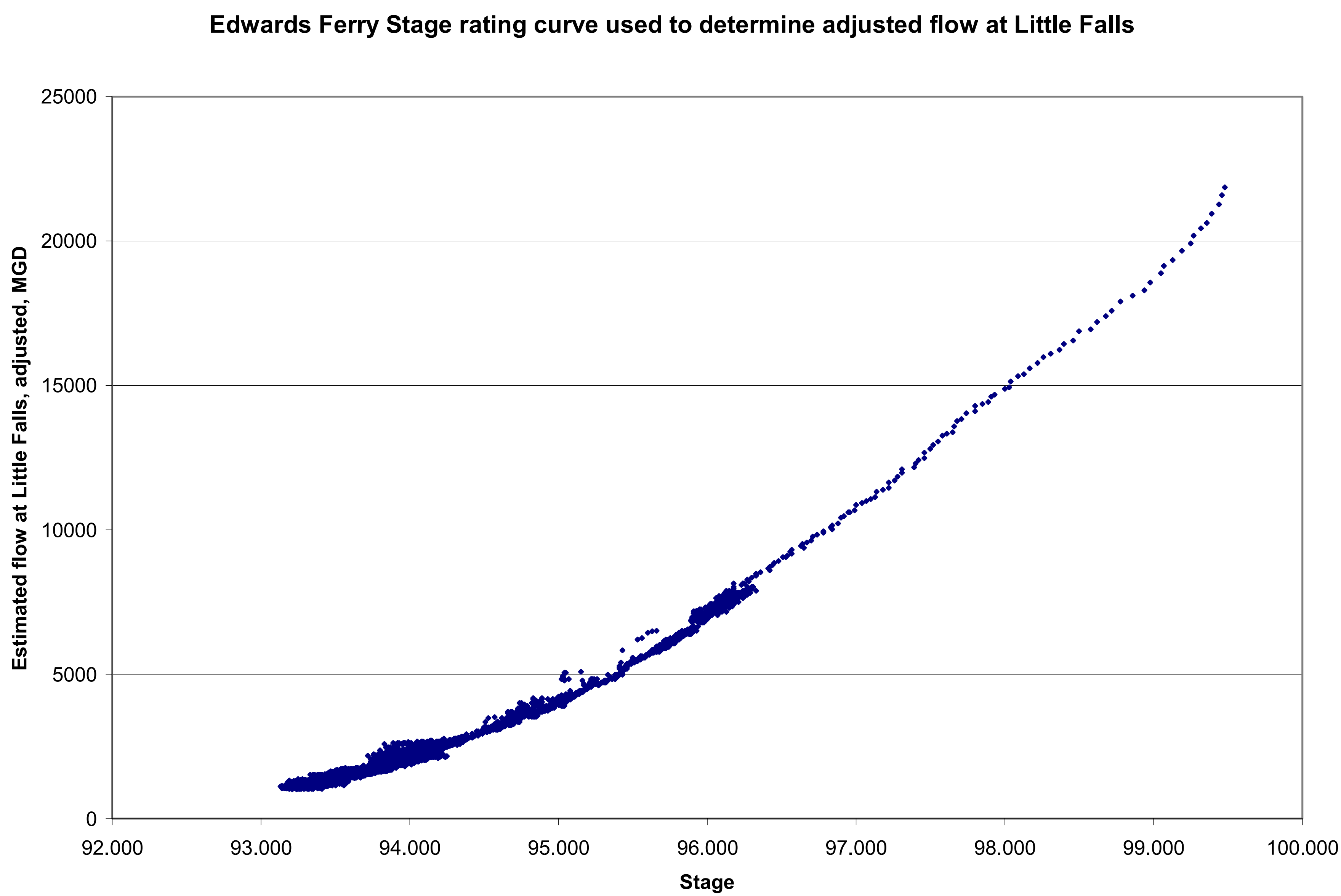



**Figure 6: Stage rating curve for Edwards Ferry used to estimate adjusted flow at Little Falls (flow range 1,000 MGD to 22,000 MGD)**

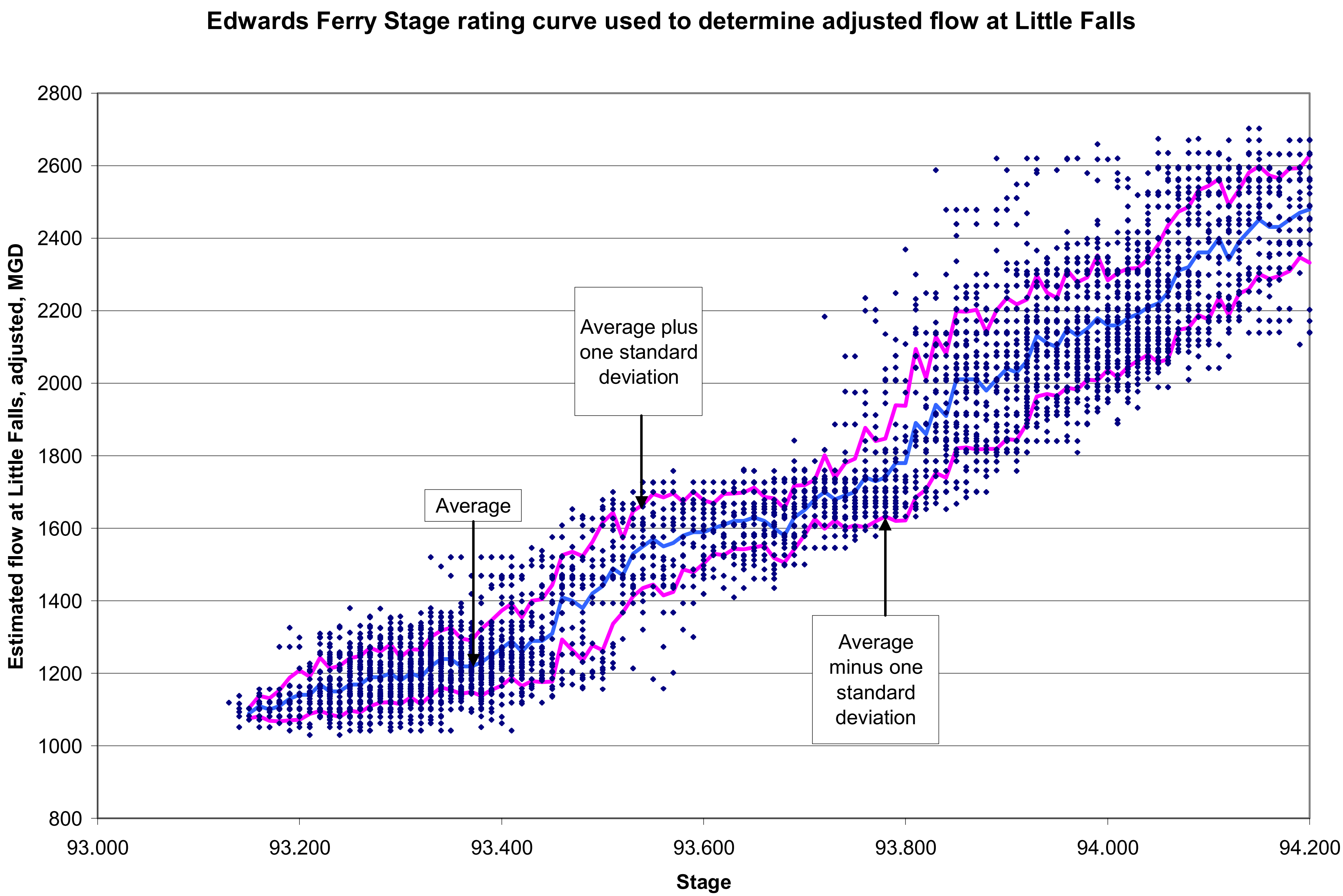



**Figure 7: Detail from Figure 6: flow range 1,000 MGD to 2,000 MGD**

**Table 1: Stage rating table for Edwards Ferry Gage**

| Stage | Little Falls flow, adjusted, MGD | standard deviation | Stage | Little Falls flow, adjusted, MGD | standard deviation | Stage | Little Falls flow, adjusted, MGD | standard deviation |
|---|---|---|---|---|---|---|---|---|
| 93.15 | 1,090 | 15 | 93.5 | 1,440 | 177 | 93.89 | 2,010 | 191 |
| 93.16 | 1,110 | 28 | 93.51 | 1,490 | 153 | 93.99 | 2,180 | 172 |
| 93.17 | 1,100 | 31 | 93.52 | 1,470 | 103 | 94.09 | 2,360 | 172 |
| 93.18 | 1,110 | 42 | 93.53 | 1,530 | 118 | 94.19 | 2,470 | 123 |
| 93.19 | 1,130 | 59 | 93.54 | 1,550 | 114 | 94.29 | 2,670 | NA |
| 93.2 | 1,140 | 68 | 93.55 | 1,570 | 125 | 94.39 | 2,800 | NA |
| 93.21 | 1,140 | 52 | 93.56 | 1,550 | 135 | 94.51 | 3,220 | NA |
| 93.22 | 1,170 | 74 | 93.57 | 1,560 | 136 | 94.61 | 3,170 | NA |
| 93.23 | 1,150 | 64 | 93.58 | 1,580 | 94 | 94.71 | 3,450 | NA |
| 93.24 | 1,150 | 71 | 93.59 | 1,590 | 111 | 94.81 | 3,680 | NA |
| 93.25 | 1,170 | 73 | 93.6 | 1,590 | 87 | 94.91 | 3,760 | NA |
| 93.26 | 1,170 | 78 | 93.61 | 1,600 | 69 | 95.01 | 4,010 | NA |
| 93.27 | 1,190 | 81 | 93.62 | 1,610 | 84 | 95.11 | 4,270 | NA |
| 93.28 | 1,190 | 70 | 93.63 | 1,620 | 76 | 95.21 | 4,640 | NA |
| 93.29 | 1,200 | 80 | 93.64 | 1,620 | 78 | 95.31 | 4,750 | NA |
| 93.3 | 1,180 | 66 | 93.65 | 1,630 | 82 | 95.41 | 5,110 | NA |
| 93.31 | 1,200 | 67 | 93.66 | 1,620 | 67 | 95.51 | 5,410 | NA |
| 93.32 | 1,190 | 75 | 93.67 | 1,600 | 82 | 95.61 | 5,720 | NA |
| 93.33 | 1,220 | 81 | 93.68 | 1,580 | 74 | 95.72 | 6,030 | NA |
| 93.34 | 1,240 | 78 | 93.69 | 1,630 | 87 | 95.82 | 6,330 | NA |
| 93.35 | 1,240 | 85 | 93.7 | 1,650 | 69 | 95.92 | 6,950 | NA |
| 93.36 | 1,220 | 76 | 93.71 | 1,680 | 54 | 96.02 | 7,330 | NA |
| 93.37 | 1,220 | 71 | 93.72 | 1,700 | 101 | 96.12 | 7,520 | NA |
| 93.38 | 1,230 | 92 | 93.73 | 1,680 | 58 | 96.22 | 7,810 | NA |
| 93.39 | 1,250 | 96 | 93.74 | 1,690 | 90 | 96.33 | 8,340 | NA |
| 93.4 | 1,270 | 103 | 93.75 | 1,700 | 92 | 96.56 | 9,250 | NA |
| 93.41 | 1,290 | 102 | 93.76 | 1,740 | 137 | 96.83 | 10,090 | NA |
| 93.42 | 1,260 | 94 | 93.77 | 1,730 | 111 | 97.07 | 11,000 | NA |
| 93.43 | 1,290 | 111 | 93.78 | 1,740 | 108 | 97.4 | 12,290 | NA |
| 93.44 | 1,290 | 114 | 93.79 | 1,780 | 160 | 97.68 | 13,780 | NA |
| 93.45 | 1,310 | 133 | 93.8 | 1,780 | 158 | 98.04 | 15,130 | NA |
| 93.46 | 1,410 | 117 | 93.81 | 1,890 | 204 | 98.5 | 16,880 | NA |
| 93.47 | 1,400 | 136 | 93.82 | 1,860 | 154 | 99.07 | 19,140 | NA |
| 93.48 | 1,380 | 144 | 93.83 | 1,940 | 188 | 99.48 | 21,850 | NA |
| 93.49 | 1,420 | 142 | 93.84 | 1,910 | 171 | | | |

## Lessons Learned

The summer pilot river level monitoring was helpful, yielding insight into the best locations for gages, strategies for reducing error in measurements, timing of when to deploy gages, and amount of time required to deploy a gage.

### Gage location and river width

The effective width of the river at low flow is an important factor in choosing a gage location. During low flows, even small differences in flows are critical for management. A gage which registers a large change in elevation for a small change in flow rate will be found at the narrower river locations. For this reason, the Edwards Ferry gage was particularly valuable. Conversely, the Great Falls gage site was not nearly as responsive to changes during low flow conditions because of a larger effective river width.

### Strategies for reducing the uncertainty in river level measurements

The standard deviation shown in Figure 7 and in Table 1 was reduced by increasing the depth of the stilling chamber in the river and using an improved stilling chamber. Figure 8 shows the stage measurements at Edwards Ferry as measured before and after these improvements were made. The variability of the stage measurement is significantly decreased by the changes. These two strategies are discussed in more detail below. During periods of intense flow management, a more frequent sampling interval can be used to better identify flow trends.

The placement of the Edwards Ferry stilling chamber was very shallow during the lowest flows. The shallow depth made the stilling chamber more susceptible to interference from waves, especially near the shoreline. When the monitor was installed in June, it was placed at approximately 2 feet below the water surface and about 6 inches above the river bottom. Without donning scuba gear, installing the stilling chamber at more than about 2 feet below the water surface (2.5 feet in depth total) is difficult. By September, this stilling chamber was about a half a foot below the water surface because of receding flow. To rectify this problem, the stilling chamber was moved into the deepest part of the channel on October 3, 2005, when flows were at their lowest.

The Edwards Ferry monitor was fitted with an improved stilling chamber when its location was moved on October 3. This should help to dampen the effects of waves and turbulence, resulting in less scatter in the stage-discharge relationship. The original stilling chamber that was used for the pilot deployment this summer is shown in Figure 9. The benefit of this stilling chamber is that it is easy to deploy, inexpensive, and adequate for cruder monitoring. The better stilling chamber that was deployed on October 3 is shown in Figure 10, which is sold by Ott. This stilling chamber is more expensive (approximately $175) and there is a risk of losing this stilling chamber during wintertime flooding, but the advantage of obtaining more accurate data is well worth the risk. The stilling chamber must be checked on an annual basis for proper alignment (The chamber must be aligned in the direction of flow) and checked for debris.  If there is much sedimentation or weeds, more frequent checking is required.

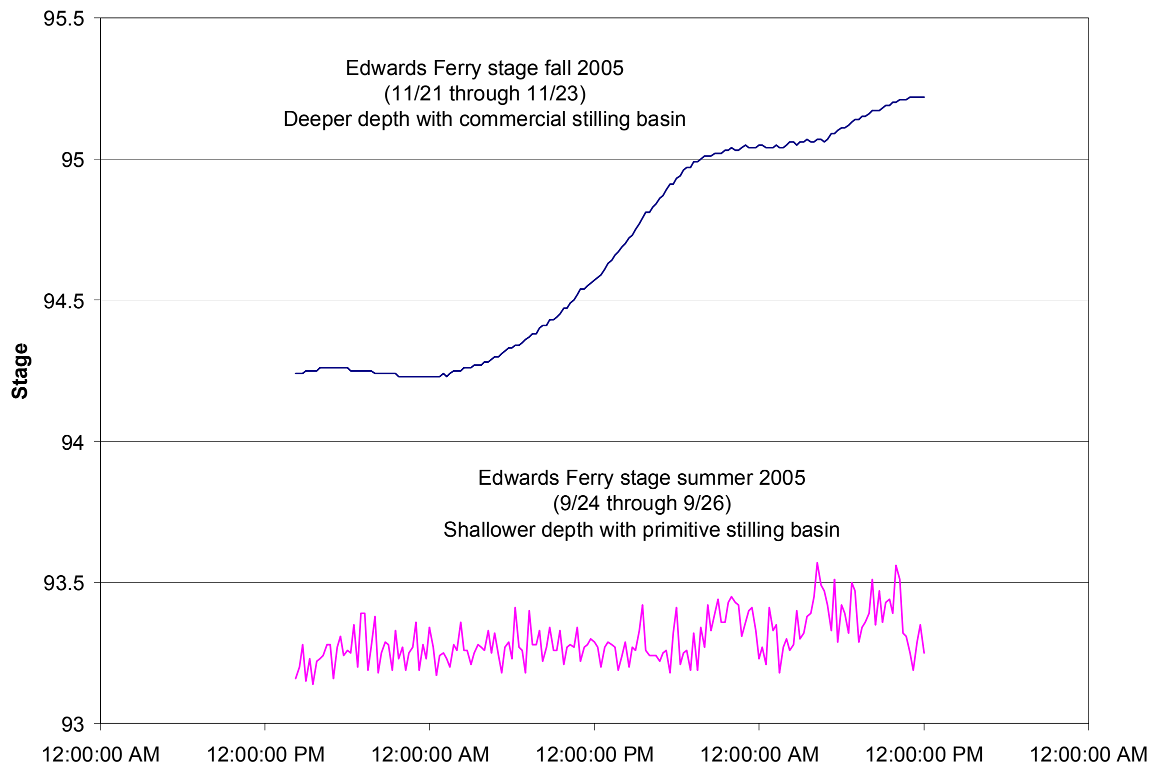



**Figure 8:  Comparison of Edwards Ferry stage measurements**

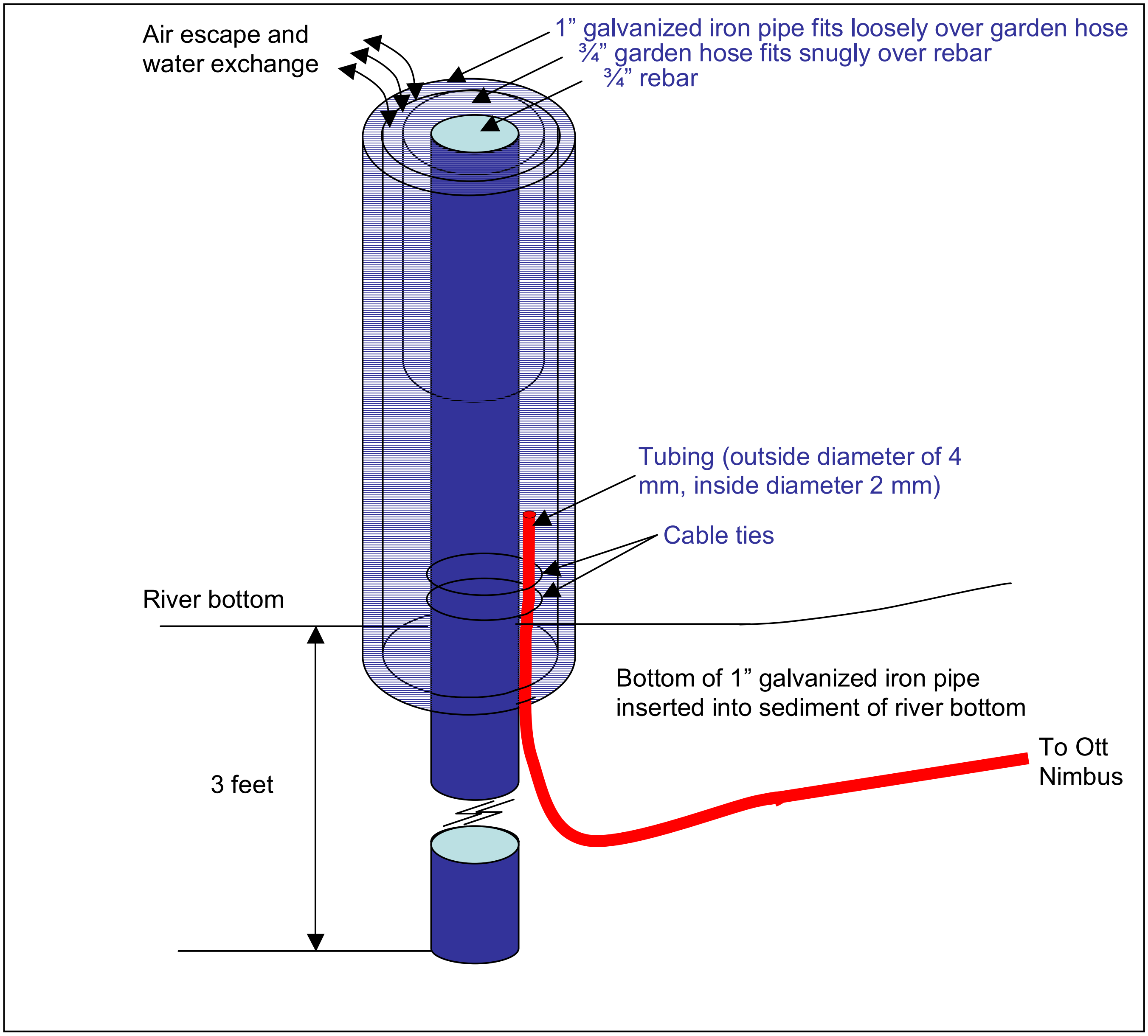
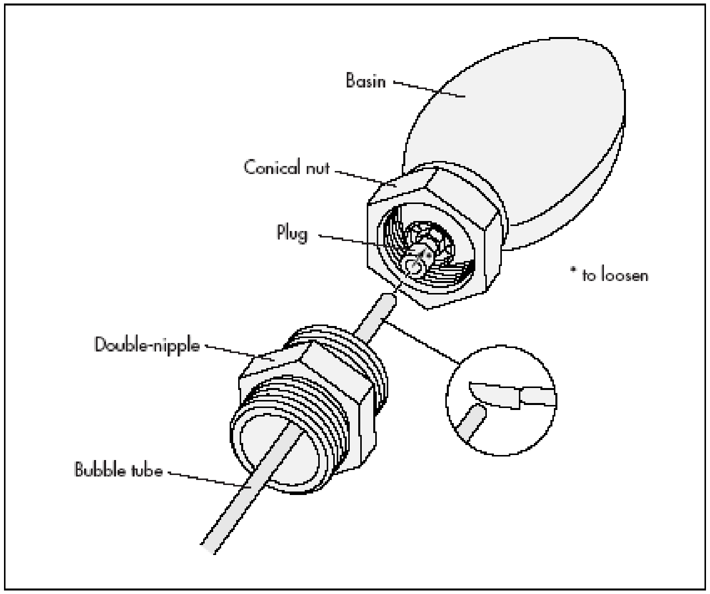
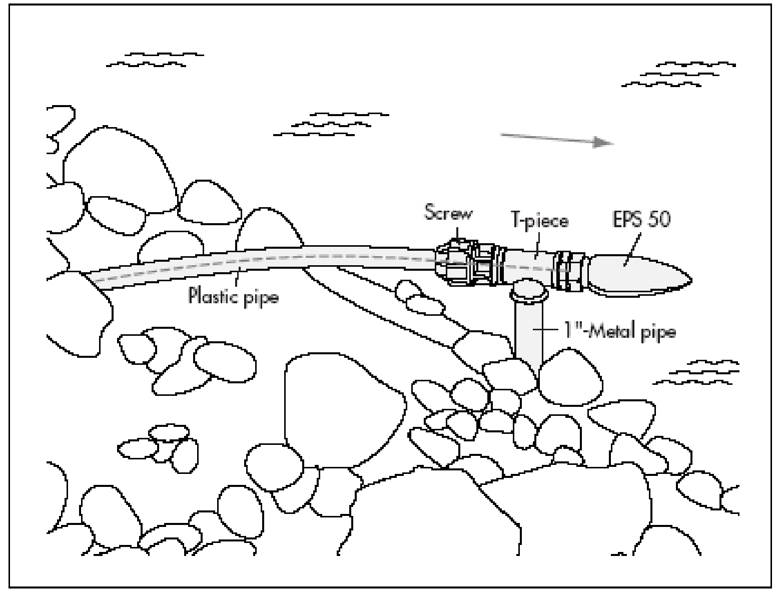



**Figure 9: Stilling chamber used in pilot deployment, summer 2005**



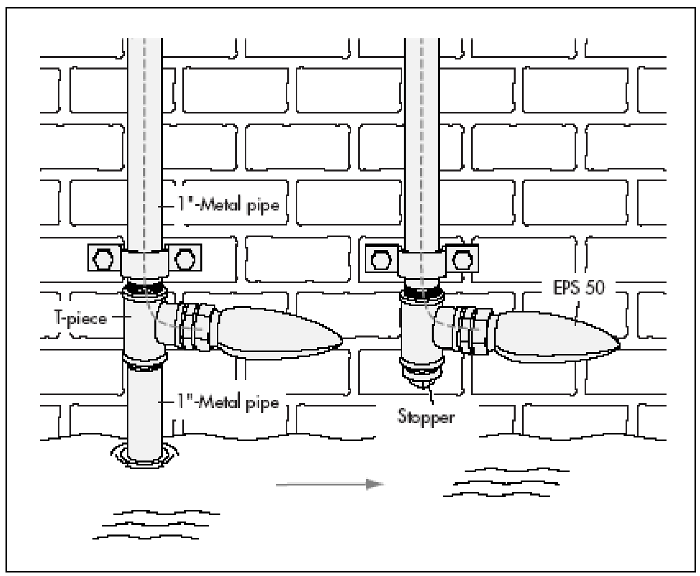




**Figure 10: Ott manufactured stilling chamber ("bubble pot"), configuration in riverbed, and configuration as mounted on a wall (image source: Ott website)**

### Timing of gage deployment

The best time to site the stilling chamber is during low flows. This allows for the deepest placement of the stilling chamber which should help to minimize the effects of increased surface turbulence from waves. Also, the gage is less likely to dry up during extreme low flows, precisely when it is needed the most.

### Time required to set up a gage

The time required to set up a river level monitor is significant and requires:

- Physical gage deployment including placement of stilling chamber, tubing, and instrumentation.
- Surveying the stilling chamber depth and relating it to a known datum.
- Office time spent obtaining data and developing a stage discharge relationship.
- Ensuring communications such as setting up the modem, connecting to the modem with the software, working out bugs with automatic report generating and automatic emergency notification procedures.

Because the time required to set up a river level monitor is lengthy and the time required to maintain and operate an existing monitor is negligable, it is optimal to keep a gage running once it is set up. Since CO-OP is extremely busy when flows start to drop in the spring, having monitors in place and running at the beginning of a drought is important so that staff effort can be devoted to flow management rather than monitor deployment.

## Conclusions/Recommendations

- Continue to maintain the Edwards Ferry and Seneca river monitor locations as they are valuable for drought operation management.
- Discontinue the Great Falls monitor as it was not very helpful for drought operation management.
- Consider adding a redundant gage at White's Ferry in case the Edwards Ferry gage is down during critical periods.
- Deploy gages during low flow periods.
- Deploy stilling chambers as deep as possible.
- Maintain gages, throughout the year, once they are deployed to avoid time consuming set-up activities.
- Increase the frequency at which measurements are taken during extreme low flows to further reduce measurement uncertainty.
- Use the stilling chambers designed by the gage manufacturer.

## Reference

Kiang, J.E., E.R.Hagen, 2003. 2002 Drought Operations Report and Lessons Learned, Washington Metropolitan Area.