Performance of Large Volume Water Transfer Systems During In-Situ Water Sampling

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Abstract

During the Joint North Pacific Research Center (J-PAC) 2002 cruise on R/V Mirai, eight Large Volume Water Transfer Systems (WTS-LV) equipped with 4 l/min. pump heads were simultaneously deployed on 14 casts. The WTS-LV pumps were positioned along the vessel's hydrowire so that they spanned a significant portion of the water column on each cast. A total of 112 samples were attempted with 108 viable samples acquired. A combined volume in excess of 56,000 liters was filtered during the casts. Each system collected engineering data, internally logging flow rate, cumulative volume, and battery voltage every 10 minutes during sample acquisition. This well correlated data set was analyzed to improve our understanding of WTS-LV system performance in real deployment situations. The field results demonstrate the ability of these systems to sample large volumes of water at various depths and with different types of filters. In addition to the analysis of these systems, this paper discusses ongoing WTS-LV development and planned improvements to the design.

I. Introduction

The Large Volume Water Transfer Systems (WTS-LV) used in this study were manufactured by the McLane Research Laboratories, Inc. (MRL). They are *in-situ*, battery powered, single sample devices that filter large volumes of water through 142 mm filters. A modular, radial intake filter holder (Fig. 1, Item 1), designed at MRL and manufactured from chemically inert materials, distributes material evenly over the surface of the filters. The pump motor with a suite of 4 interchangeable pump heads (Fig. 1, Item 2) spans a flow rate range of 2 to 30 liters per minute. Single samples larger than 40,000 liters have been filtered in the deep ocean. Several different types of filters, including membrane, fiber, and mesh, can be used with the WTS-LV to meet the requirements of particular investigations. The design allows investigators to match flow rates, pump heads and filter types to particular applications, achieving greater accuracy and reliability.

During sampling the system continuously monitors pump performance. A closed loop, proportional-integral control algorithm maintains the programmed flow rate, automatically adjusting the set point as necessary to preserve sample integrity and volume accuracy. The system is mounted on a 316SS frame (Fig. 1, Item 4). During the deployment the WTS-LV is clamped to the hydrowire using a variable wire-size clamp (Fig. 1, Item 5). The pump is controlled and data are logged by a Tattletale 8 electronics stack powered by drop-in alkaline batteries. These components are housed in a hard-coated aluminum housing (Fig. 1, Item 3). An external flow meter (Fig. 1, Item 7) is installed on the output of the pump head to provide a measure of the sample volume independent of the WTS-LV's control system. An optional cartridge holder (Fig. 1, Item 6) can be installed between the filter holder and the pump head to hold absorption cartridges. A more detailed description of the WTS-LV can be found in [1].

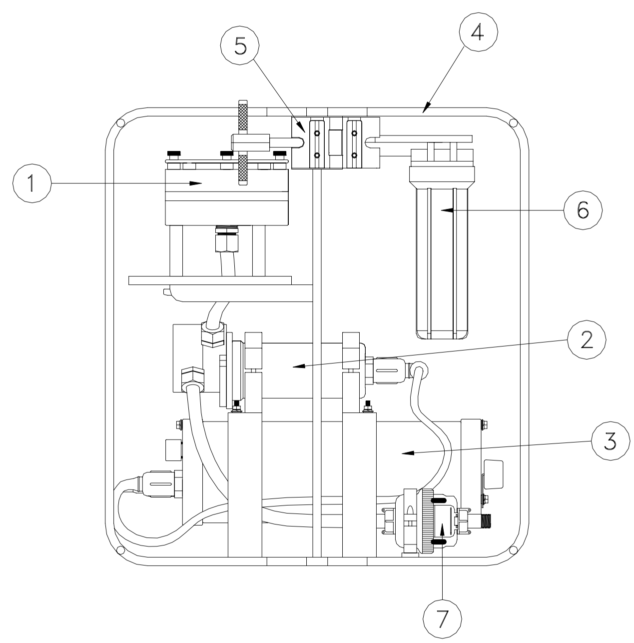

Fig. 1: McLane WTS-LV System Diagram

Item 1 – Radial Intake Filter Holder
Item 2 – Rotary Pump w/ Interchangeable Pump Heads
Item 3 – System Controller w/Aluminum Housing
Item 4 – 316 Stainless Steel Frame
Item 5 – Variable Wire Clamp
Item 6 – Optional Cartridge Holder
Item 7 – External Flow Meter

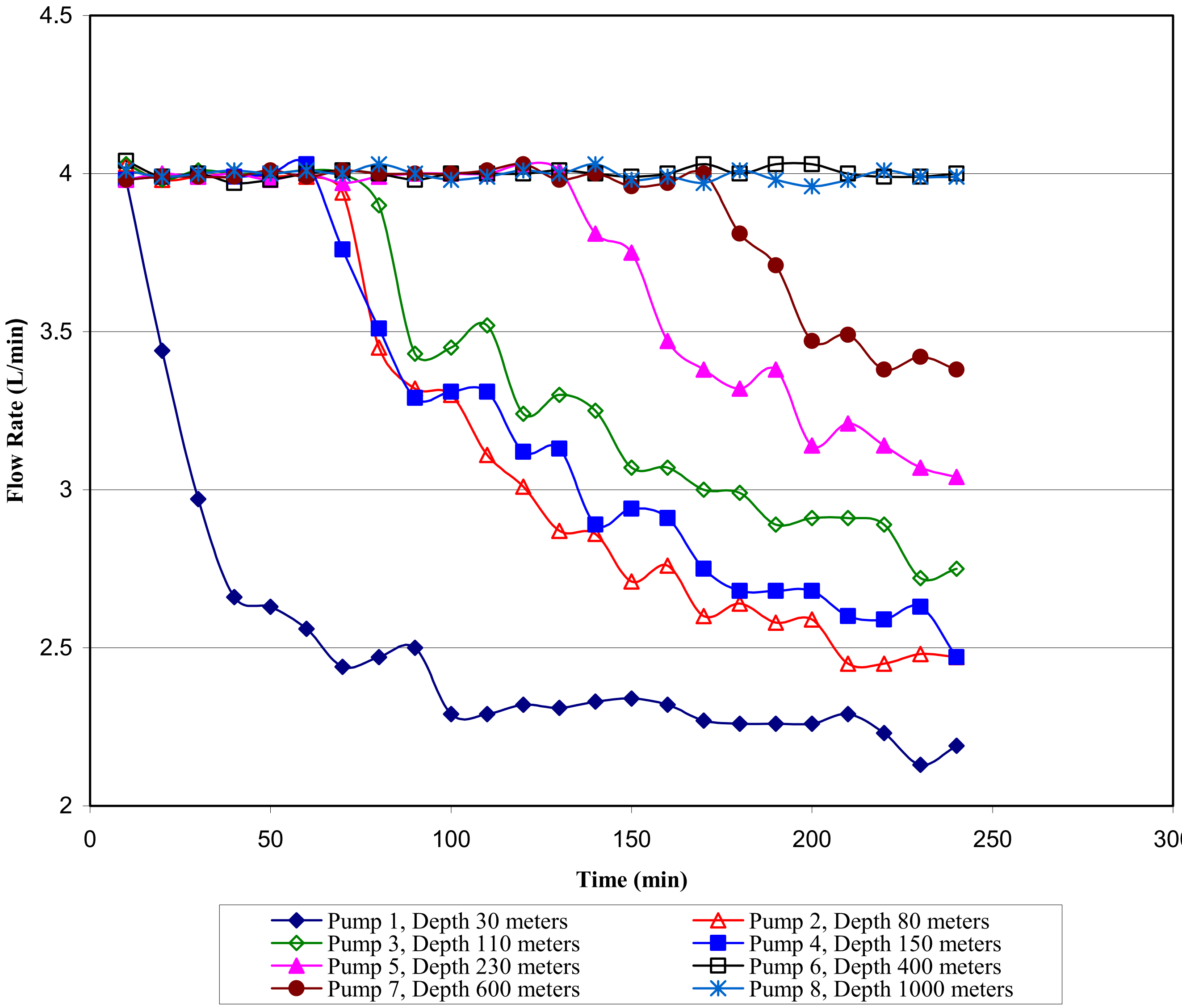

Fig. 2: Station K1, Cast 5
Flow Rate Variance Throughout Sampling Time Period for an Eight WTS-LV Cast.
Filter Type – Acrylic Copolymer 0.8 µm Pore size

II. Deployment

The J-PAC North Pacific cruise on the R/V Mirai departed from Dutch Harbor, Alaska on October 11, 2002. During the next 27 days, 14 large volume pump casts were performed at 4 different stations in the North Pacific [2].

Station	Location	Dates on Location	No. of Casts
K1	51°N, 165°E	Oct. 16 – Oct.20	7
K2	47°N, 159°E	Oct. 21 – Oct. 26	2
K2.5	43°N, 160°E	Oct. 26 – Oct. 27	2
K3	39°N, 160°E	Oct. 28 – Nov. 2	3

For each cast eight WTS-LV systems were individually clamped to the vessel's hydrowire. Locations along the wire were selected to sample the depths of interest. Depth sensors were attached to the maximum and median depth pumps to check the ship's hydrowire depth calculation. Several different configurations were used. For example, during a shallow cast the systems were positioned at different depths between 10 and 75 meters. During a deep cast the systems spanned depths between 1500 and 5200 meters.

The systems were programmed to begin pumping after a set countdown interval (the time needed to deploy the array). Rather than selecting a common sample volume, the pumps were programmed to operate for a fixed time limit, which varied from one hour for shallow casts to eight hours for deep casts. The systems were also programmed to maintain a flow rate of 4 l/min. without exceeding a pressure differential of 10 psi across the sample filter. Automatically limiting the differential pressure allows the WTS-LV to maintain high volume and flow rate accuracy, enhancing the scientific value of the sample. Limiting the differential pressure also prevents damage to physically delicate samples (e.g. plankton).

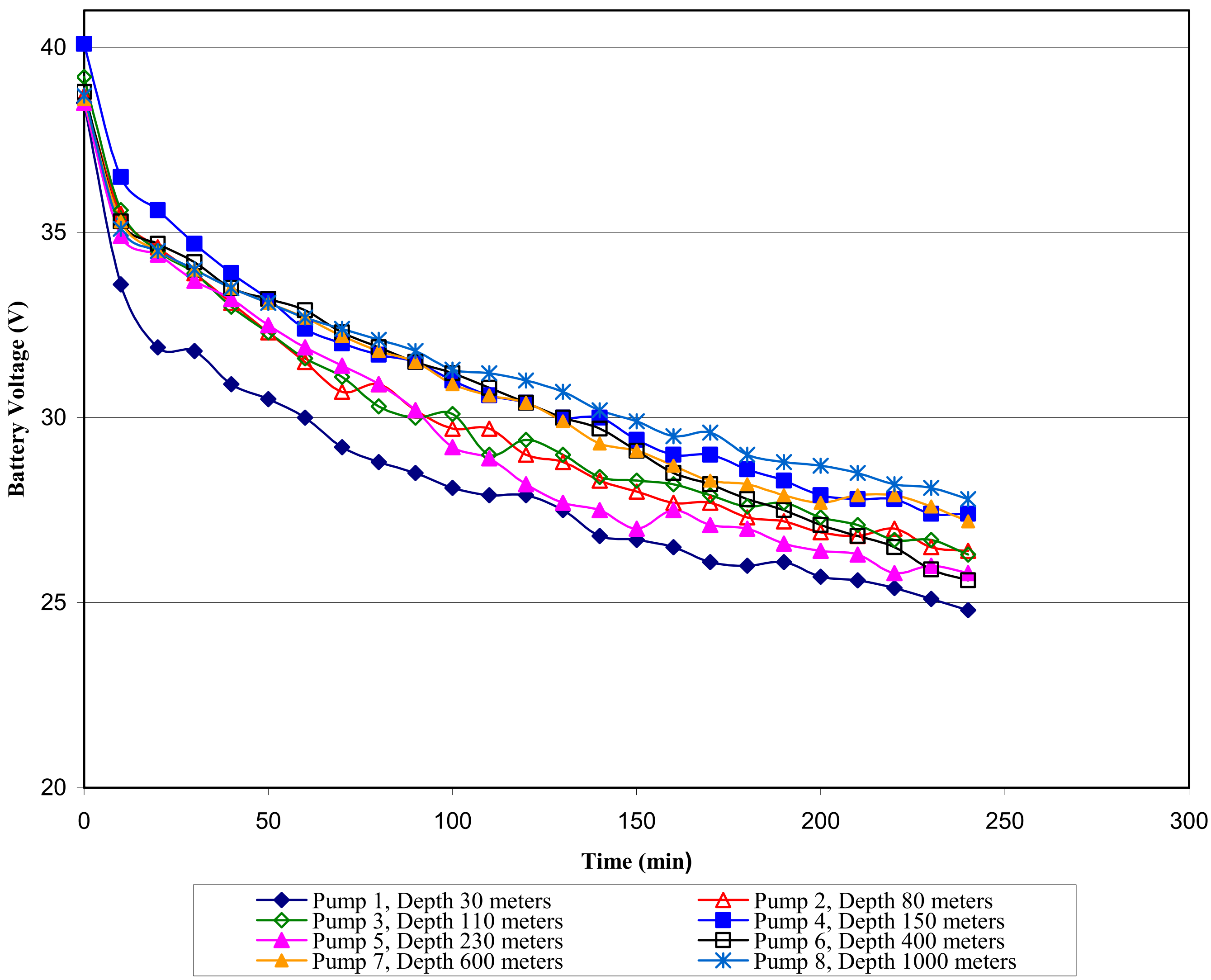

Fig. 3: Station K1, Cast 5
Battery Voltages Throughout the Sampling Time Period for an Eight WTS-LV Cast.
Filter Type – Acrylic Copolymer, 0.8 µm Pore size

After recovery the sample filters were immediately and carefully removed from the filter holders and stored for later scientific analysis.

Four investigators used the WTS-LVs during the cruise. Each used a different type of filter. The filters were matched to the specific goals of the studies being conducted. Acrylic copolymer filters (0.8 µm) were used to collect barite crystals, which were then analyzed for radium isotopes. Samples from the same acrylic copolymer type of filters were also used to determine particle concentration of various nuclides. Glass fiber filters (~0.78 µm) and polycarbonate membrane filters (5 µm) were used to sample for nitrogen isotopes and to determine the flux of POC (Particulate Organic Carbon) via the concentration of ^{234}Th (a particle-reactive radionuclide) [3].

III. Analysis

While sampling, each system internally logged battery voltage, flow rate, and cumulative volume. The cumulative volume was also independently recorded from the external flow meter. This engineering data was collected upon recovery and analyzed to further understand the behavior of the WTS-LV system.

This large, comprehensive, and coherent data set presented a unique opportunity to analyze the performance of the WTS-LV under real deployment conditions. The systems were able to successfully collect 108 scientifically viable samples and filtered over 56,000 liters of water. The largest samples collected in this data set were each over 1200 liters.

Table 1: Station K1, Cast 5 – Cumulative Volumes

Pump No.	Depth (m)	Total Cumulative Volume (L)
1	30	151.40
2	80	475.40
3	110	501.13
4	150	543.53
5	230	600.68
6	400	617.71
7	600	637.77
8	1000	799.01

The WTS-LV control algorithm performed as expected. Programmed flow rates were precisely maintained where possible. When made necessary by the accumulation of material on the filter, flow rates were smoothly and automatically reduced to keep the differential pressure below the 10 psi limit while maximizing the total sample volume. This is shown clearly in Fig. 2. The shallow systems, where greater particulate concentrations are expected, reduced the flow rate sooner and to a greater extent than the systems located deeper in the water column, where less rapid accumulation of material is expected. This trend is consistent across the data set for all the hydrowire casts at all four of the locations. Examination of the flow rate and battery voltage time series demonstrated that the control algorithm was able to accurately maintain the programmed flow rate as the battery voltage steadily declined during sample acquisition (Fig. 3).

Analysis of battery voltage records for the 108 successful samples showed that the endurance of the D-Cell drop-in pack is approximately 8 hours. During some of the eight hour casts the system experiencing the most severe load (greatest accumulation of material) exhausted the battery and performed an automatic shutdown 20-30 minutes before reaching the programmed time limit. However, it should be noted that battery endurance can vary significantly. Endurance is dependent on several factors including battery drain, particulate accumulation, filter type, and cartridge characteristics. For example, with a large pore size filter, no absorption cartridges, and low accumulation of matter, the WTS-LV's battery endurance will significantly exceed the 8 hours.

Unfortunately, the pattern of filter use on this cruise does not permit correlation of the WTS-LV performance with filter type. Most of the short, shallow casts were done with one type of filter while the mid-depth and deep casts were performed with other types. However, the results do demonstrate the ability of the WTS-LV to successfully operate using all of the filter types used on this cruise.

The WTS-LV system dynamically calculates the flow rate, cumulative volume, and differential pressure based on the known geometry of the pump head, the measured shaft speed of the motor, and an experimentally determined leak rate. Comparison of the system's calculated sample volume with the sample volume recorded by the external flow meter for each of the casts shows that this model is not accurate under all conditions. In some cases, mostly those where the system encountered low differential pressures across the pump head, the two volumes are consistent. However, in other cases they may disagree by as much as 70 percent. This inconsistency reinforces the need for the external flow meter as well as encouraging a re-evaluation of the approach used for the dynamic internal calculations.

IV. Future Development

It is evident from the data acquired during the J-PAC North Pacific Cruise that the dynamic determination of the pump head leak rate needs to improve. This might be done by collecting a larger experimental data set, using longer pumping times, and sampling over a larger range of differential pressures. The current model uses a single nominal leak rate independent of actual differential pressure across the pump head. This assumption creates inaccuracies in the calculations of flow rate, cumulative volume, and differential pressure that vary with deployment conditions. However, the complexity of a variable leak rate calculation coupled with the short duration of the control loop interval argues against this approach.

Integration of a differential pressure sensor, installed across the pump head, is under development. The leak rate is a nearly linear function of differential pressure (and possibly flow rate). With this sensor installed the control algorithm would have direct access to the variables needed to accurately calculate the actual flow rate. The limiting differential pressure could also be set by the operator to meet the requirements of a particular investigation. This would improve the system's accuracy and flexibility. Unfortunately, the required characteristics of such a pressure sensor are rather extreme; it must be able to detect small changes in differential pressure (1psi accuracy) over a large range of ambient pressures (0 to 10,000 psi). Also, during deployment and recovery, large pressure spikes can conceivably occur across the pump head. The sensor must be able to survive those spikes without loss of accuracy. We are not aware of any commercially available sensor that can meet these requirements without significantly increasing the cost of the WTS-LV system.

V. Conclusion

The data collected from the WTS-LV systems on the J-PAC 2002 Cruise on the R/V Mirai demonstrate the reliability of these systems in real deployment conditions. The collection of 108 viable scientific samples on different filter types and in diverse deployment conditions amply demonstrates the WTS-LV's capabilities. The integration of a differential pressure sensor across the pump head will increase accuracy and flexibility, further enhancing the utility of the WTS-LV for oceanographic and limnological research.

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