Water Tracing, *In Situ* Dye Fluorometry and the YSI 6130 Rhodamine WT Sensor

Introduction

The growing interest in the development of accurate waste load and assimilative capacity models, as well as in models for determination of transport and fate of instantaneous pollutant discharges, has increased the need for the accurate characterization of water movement. In the United States, programs such as National Pollutant Discharge Elimination System (NPDES) and Total Maximum Daily Loads have been a significant impetus behind this interest. Water tracing using dye fluorometry is the most common method by which data are collected for these purposes.

The extensive use of fluorescent dyes as water tracers began in the early to mid-1960s (Pritchard and Carpenter 1960). Prior to that time, floats, chemical salts, and actual contaminants had been used as tracers. Radioisotopes, i.e., tritium ("heavy hydrogen"), became popular after WWII but their use was limited due to handling problems, training requirements and public misunderstanding (Wilson, et. al. 1986). Dye fluorometry was first applied for measurement of time of travel (TOT) of solutes in streams and, to date, this remains its most used application. Although a number of dyes are available for fluorometric hydrologic studies, Rhodamine WT is recommended because it is easy to use and has many features which are desirable for water tracing (Wilson, et. al. 1986), and because it is the most conservative of dyes available (Kilpatrick and Wilson 1988).

Until the advent of *in situ* Rhodamine WT measurement systems, dye fluorometry hydrologic measurements were performed exclusively by the analysis of multiple samples physically extracted from the water body, at multiple locations, as the dye plume was naturally dispersed. To date, the greatest percentage of these investigations are performed using fluorometers designed for *in vitro* and pump-through measurements. Although these methods predominate today, and can produce accurate hydrologic data, they are resource-intensive, significantly vulnerable to human error and other natural phenomenon, and necessitate the field deployment of personnel throughout the duration of the study which increases risks to safety. The advent and recent employment of *in situ* measurement systems has accentuated the limitations of *in vitro* and pump-through methods for performing these studies. As the demand for the quantity and quality of hydrologic data increases, investigators have begun to search for alternatives, and have indicated that *in situ*, unattended measurement will be the method of choice for future dye fluorometry hydrologic measurements.

Applications for Rhodamine WT dye tracing include, but are not be limited to: TOT (surface water and groundwater); reaeration studies; dispersion studies; discharge measurements (by dye-dilution methods); waste buildup and flushing in estuaries and bays; wastewater retention and flushing in wetlands; combined and sanitary sewer overflows; tracing circulation and stratification in reservoirs; path tracing in karst (cavernous limestone); determination of well-drilling fluid circulation time; irrigation water uptake by plants; tagging and tracing herbicide, and tracing heated water.

Fluorescence and Fluorometry Basic Theory

The term fluorescence generally refers to a form of luminescence, i.e., any emission of light not directly ascribable to heat (Wilson, et. al. 1986). Upon irradiation from an external source, a fluorescent substance (i.e., Rhodamine WT) will fluoresce, that is, emit radiation (light) of lower energy (longer wavelength). In accordance with Stoke's Law, the energy emitted by electrons returning to the ground-state is of a lower energy (longer wavelength, lower frequency) than that which caused the excitation state. When irradiance ceases, fluorescence ceases.

It is this property of dual spectra – a different specific combination of excitation and emission spectra for each fluorescent substance – and the near instantaneous nature of this sequence of events, that describes the principle behind fluorometric measurements, and that is used to make fluorometry an accurate and sensitive analytical tool (Undefriend 1962, Wilson et. al. 1986). Each fluorescent substance is characterized by a specific excitation spectrum and specific emission spectrum. The excitation spectrum is the variation in intensity of emitted light with the wavelength of the absorbed light. The emission spectrum is the variation in intensity of emitted light with the wavelength of the emitted light (Wilson et. al. 1986).

All dye fluorometry methods, whether designed for discrete or flow-through *in vitro* measurement or *in situ* measurement, adhere to the principals described above. The characteristics or properties of the dye being considered for the application are tantamount in importance. If the spectral properties of the dye are such that a dye-specific excitation energy can be selected for transmission into the water, and dye fluorescence-specific filters can be selected to receive emission energy (fluorescence) from the dye, the fluorometer can be configured for the near-exclusive measurement of the concentration of that dye. This special configuration can greatly minimize interferences that would compromise data quality and accuracy.

Specifically about Rhodamine WT

Of the multitude of fluorescent dyes on the market today, few exhibit the features that are essential for dye fluorometry hydrologic studies. Although a number of dyes have utility in certain applications, over the years two dyes, both variations of the same molecular structure (xanthene), have surfaced as the fluorescent dyes of choice for these studies: intracid rhodamine B and Rhodamine WT. Of these, Rhodamine WT is preferred for most dye fluorometry hydrologic studies due to its ease of use, relatively low cost, low adsorptive tendency, strong fluorescence, high diffusity, chemical stability, and benign character in the aquatic environment (Parker 1973, Smart and Laidlaw 1977, Wilson, et. al. 1986, Kilpatrick and Wilson 1988).

In addition, the spectral characteristics of Rhodamine WT are unlike those found with *most* other substances in ambient waters (surface water, groundwater, estuarine and marine water), making it well-suited for use as a water tracer (Wilson, et. al. 1986).

Water Tracing and Dye Fluorometry for Hydrologic Studies

Basic Theory

Though dosing and sampling procedures and data analysis methods vary with application, in general, the standard procedure in dye fluorometry hydrologic studies is to introduce a quantity of dye into a water body, and subsequently collect water samples over some spatial and temporal regime. These samples are then analyzed with a fluorometer for the concentration of the dye that is proportional to its fluorescence.

Dyes mimic the movement of water molecules. A measure of the movement of a dye (i.e., Rhodamine WT) will in effect be a measure of the movement of the water and, therefore, substances transported by the water in which it is introduced. Dispersion and mixing occur in all dimensions of the water body (Wilson, et. al. 1986). For example, in streams vertical mixing typically occurs first. Subsequently, and depending on current, channel configuration and stream characteristics, lateral mixing and longitudinal mixing follow. These phenomena are the subjects of interest to investigators employing dye fluorometry. For other bodies the sequence of mixing phenomena may vary, but the principle holds true nevertheless.

The concentration of a dye used as a water tracer is directly proportional to its fluorescence. Therefore, a plot of dye concentration (or fluorescence) made in spatial and temporal context can reveal the TOT and dispersion characteristics of the water or of a water-borne substance under the conditions in which the study was performed. With care, theoretical models or simulations of TOT and dispersion responses, under conditions differing from those during actual studies, can be developed. These serve as useful tools for understanding aquatic system mechanics and responses to perturbation under different and varying flow conditions.

Factors Affecting Rhodamine WT Fluorescence in Ambient Waters

There are a number of physicochemical factors that must be considered when performing dye fluorometry hydrologic studies. A complete identification of these factors and the mechanisms by which they interfere with dye fluorescence and fluorometry is beyond the scope of this work. However, this topic is discussed in great detail in numerous publications such as those listed in the References section of this document. Suffice to say that fluorescence is affected in varying degrees by certain physicochemical factors, listed as following in relative order of importance: concentration, water (sample) temperature, interference, quenching, photochemical decay, sorption, pH and dissolved oxygen. Please note that season-specific and climate-specific conditions, as well as the extent of perturbation, will necessarily shift the relative importance of these factors.

Concentration is paramount in importance in dye fluorometry hydrologic studies. Dye fluorescence varies directly with dye concentration. Great care must be taken to insure that an adequate volume of dye is being used to permit accurate and precise measurement of dye concentration (fluorescence) for the duration and extent of the study, and that concentration is not so high as to exceed detectable limits of the fluorometer.

Second only to concentration in importance is *temperature* among factors affecting dye fluorescence (Wilson et al. 1986). Fluorescence activity increases, indicating an apparent higher dye concentration, as water (sample) temperature decreases. As water (sample) temperature increases, fluorescence activity decreases, indicating an apparent decrease in dye concentration. Water (sample) temperature compensation must be performed, or significant measurement errors are likely to occur.

Fluorescent substances found in aquatic systems, that might share excitation or emission spectra with Rhodamine WT, and thereby be source of *interference*, include, but are not limited to: algae; certain salt compounds; naturally occurring colored organic compounds, and manmade organic pollutants (i.e., dyes, petroleum distillates, detergents).

As stated in a previous section, each fluorescent substance

is characterized by a specific excitation and a specific emission spectrum. That not withstanding, many fluorescent substances share some part, albeit often a small part, of the excitation and/or emission spectrum of another substance. This is a potential source of error that must be considered when performing dye fluorometry hydrologic studies.

Quenching is the suppression of fluorescence, and results from the action of other substances in solution with the dye. Quenching agents may act in any or all of the following manners: (1) absorb excitation energy; (2) absorb emission (fluorescence) energy; (3) degrade excitation-state energy; and (4) chemically alter the dye molecular structure (Williams and Bridges 1964). Chlorine is an example of a quenching agent that changes fluorescent properties of Rhodamine WT by altering its molecular structure.

Great care must be taken to use distilled or deionized water when preparing dye dilutions for injection to the water body to avoid the effects of chlorine. As well, it is important to account for these effects when studying chlorinated effluents and waters receiving chlorinated effluents.

Photochemical decay or photodecomposition results from exposure of the dye to bright sunlight for extended periods of time and can cause permanent reduction in fluorescence (Wilson et al 1986). Generally speaking, stream depth, turbidity, cloud cover, shading by riparian canopy and duration of study are all factors affecting dye exposure to sunlight, therefore, influencing the extent, if any, of photochemical decay. It is important to note that Rhodamine WT is particularly susceptible to photochemical decay.

Water tracing dyes have a tendency to adhere to (adsorption) or to be incorporated in (absorption) suspended matter, sediments, aquatic plants and aquatic animals which results in the physical loss or attenuation of dye as it moves through or within the water body. *Sorption* (adsorption or absorption) is not a factor affecting fluorescence; rather the effects are similar to those from photochemical decay or quenching, in that there is a decreased recovery of dye. Dye losses by sorption, photochemical decay and quenching have a direct impact on the accuracy of discharge measurements, but are rarely significant enough to impact TOT, dispersion or reaeration measurements. Dye loss is a critical factor in groundwater studies (Wilson et al. 1986).

As a rule, organic sediments tend to adsorb more dye than inorganic sediments. Although sorption can be a factor affecting dye fluorometric studies, fortunately Rhodamine WT is only slightly susceptible to sorption in most situations (Wilson et al. 1986).

Turbidity can be a significant source of physical interference. Substances comprising water turbidity can themselves be fluorescent or not. Interference by those that exhibit fluorescence has been discussed previously. Those substances or particles suspended in the water column that are not fluorescent nevertheless reflect and refract light to varying degrees based on their quantity, shape, size, motion (if any) in and through the water, and particle density. If turbidity is high enough and/or enough of these compounding factors are involved, transmitted as well as emitted light will be inhibited. Therefore, interference from turbidity must be rejected at the point of measurement, or fluorescence data must be corrected for the effects of turbidity.

The *pH* of a sample may also affect fluorescence intensity, therefore the measured concentration of dye. Fluorescence of Rhodamine WT is stable in the pH range of 5-10 and decreases outside those limits (Feuerstein and Sellek 1963). Decreased fluorescence due to pH variation is generally not a problem except in studies of instantaneous pollutant discharges; industrial waste streams; acidic streams, and certain stages of municipal and industrial waste treatment.

In highly aerated waters, such in the whitewater reaches of mountain streams or in other situations where super-saturation of *dissolved oxygen* exists, oxygen can manifest the same effect as chlorine (Wilson et al. 1986). Care should be taken to identify stream reaches where there is potential for this problem and to quantify its effects.

Applications

Dye fluorometry hydrologic studies are conducted to provide data for waste load and assimilative capacity models, as well as to estimate the passage (transport, mixing, diffusion) of noxious substances instantaneously discharged to a water system or water body. The representative accuracy of a water quality model is typically no better than the hydrologic data on which it is based (Wilson et. al. 1986). Assimilative capacity, estimates of retention, and transport of suspended sediments and nutrients, as well as many other aspects of an aquatic system that are addressed in water quality models, are all highly dependent on accurate hydrologic data.

For purposes of this discussion, applications for dye fluorometry can be placed into three general categories: surface water, wastewater and groundwater. Surface Water includes freshwater, brackish water, seawater, and non-point source pollution (not including municipal stormwater). Wastewater includes municipal and industrial wastewater; combined sewers; industrial pretreatment, and municipal stormwater. The Groundwater category represents all groundwater studies including, but not limited to, natural systems, wastewater injection, landfill monitoring and remediation.

Surface Water

The impetus behind surface water applications of dye fluorometry is largely the need to develop the water quality and waste load models used to describe surface water system response to perturbation, and to help with the establishment of criteria necessary for restoration and/or protection of surface water systems. Time of travel (TOT) studies are an integral component of this work and are performed exclusively using dye fluorometry. In the US, programs such as NPDES and TMDL continue to increase the need for dye fluorometric hydrologic measurements.

Though their data will have different applications, dispersion, mixing, reaeration and circulation studies all seek to determine the distribution characteristics of a physical and/or chemical feature, phenomenon or substance — be it natural or anthropogenic, within, and often out of, an aquatic system. Dispersion and mixing studies are typically aimed at understanding more about the likely distribution of pollutants, for example a spill, by-pass, or heated effluent discharge. Mixing studies, though similar and often considered integral to distribution studies, are often designed more to estimate and demonstrate the downstream distance where mixing – as defined by various criteria – occurs.

Reaeration studies are performed in a wide variety of surface water systems, such as hydroelectric reservoirs, lakes, streams, bays and estuaries. Reaeration studies using dye fluorometry are designed to determine the dispersion and mixing of a gas or gases, usually of oxygen, within and out of the system. For example, dye fluorometry reaeration studies are used to evaluate the efficacy of practices such as air injection employed to mitigate suppressed DO levels. These studies may be performed using the actual gas under consideration (i.e., oxygen) or may use a tracer gas such as butane to mimic the dispersion, mixing and dissipation characteristics of the actual gas under consideration.

Surface Water Applications

- Time of travel (TOT) studies
- Dispersion: i.e., discharged contaminants, turbidity from dredging and runoff
- Mixing zone identification, characterization
- Reaeration studies: i.e., reservoirs, lakes, streams, bays
- Circulation patterns: i.e., lakes, reservoirs, bays and estuaries
- Discharge measurements (by dye-dilution methods)
- Bay and estuary hydraulics
- Wastewater and stormwater retention in wetlands
- Irrigation water uptake by plants
- Tagging and tracing herbicide migration and dispersion
- Spill mapping and response

Wastewater

Flow analysis and characterization in municipal and industrial wastewater facilities is part of the operational SOP. The effectiveness and efficiency of a treatment facility depends largely on adherence to hydraulic design. Phenomenon such as "short-circuiting" profoundly affects a facility's performance. Short-circuiting can be detected relatively quickly and corrective measures assessed through the use of dye fluorometry. This work is driven by operational requirements, as well as effluent quality regulations, therefore it is not typically as government program-dependent as are many hydrologic studies such as TOT.

Monitoring stormwater hydraulics, retention times in stormwater catchments, and stormwater quality are critical components of municipal and industrial pollution abatement programs. Dye fluorometry is a valuable tool for making the measurements necessary to model these pollution sources, as well as to test the effectiveness of treatment methods.

Unfortunately, sewage collection system overflows are a common occurrence, and are often due to undersized or dilapidated collection systems. One factor contributing to these overflows is infiltration-inflow to the system by surface water and groundwater. This is particularly acute during storm events and flooding where water enters the collection system from the surface (manholes and open covers) and through cracks in the pipes. Often dye fluorometry is used to assess hydraulic capacity of collection systems, as well as identify quantities and sources of infiltration-inflow.

In many cities throughout the world stormwater and sewage are combined. Hydraulic capacities of these systems are often exceeded during storm events, and discharges from them often occur. Dye fluorometry is used to assess hydraulic capacity of these systems, to identify quantities and sources of infiltration-inflow to the system, and to determine the dispersion of discharges (overflows) from them to groundwater and surface water.

Wastewater Applications

- Hydraulic characterization of WWTF (Wastewater Treatment Facilities) for operational, environmental purposes
- WWTF aeration and reaeration basin mixing studies
- WWTF contact chamber residence time analysis, operational, environmental purposes
- WWTF influent plume tracing, operational purposes
- Wastewater collection system discharge measurements (by dye-dilution methods)
- Combined and sanitary sewer overflows
- Stormwater hydraulics, pond retention time

Groundwater

Although it is common knowledge within the scientific community that contamination of groundwater will lead to the same in surface water, and vice versa, the ignorance or disregard of this fact has facilitated many practices in resource exploitation and waste disposal that have resulted in the contamination of groundwater and surface water systems around the world. It is for this reason primarily that the communication between surface water and groundwater systems have been under investigation for many years.

The determination of TOT, direction, path and dispersion of groundwater is particularly difficult. With the exception of some karst regions, where groundwater movement may be more similar to surface water streams, most groundwater movement is remarkably slow and characterized by complex dispersion patterns. Varying geologic strata, wells, pumping, mining and surface features that facilitate or inhibit recharge, all affect groundwater current, direction and dispersion, thereby greatly complicating the study of pollutants within groundwater systems.

One of the most effective means by which groundwater and the movement of groundwater contaminants can be studied is through the use of dye fluorometry. Although fluorescein has been more commonly used in groundwater tracing applications, Rhodamine WT is widely used and in some cases may be preferable since fluorescein is a common constituent in both sewage and landfill leachate (Duley et al. 1999). Sorption to soil and bedrock, and quenching by chemical degradation of dye by groundwater contaminants are the principal sources of error in dye fluorometry groundwater tracing. These "losses" are exacerbated by the typically long TOT and complex dispersion patterns of groundwater. For these reasons, *in situ* dye fluorometry in groundwater has less utility than in surface water and wastewater applications. There are exceptions, however, such as in landfill leachate and surface pit disposal studies where TOT is relatively short, dispersion patterns are less complex, and where down-hole measurements of dye concentrations are needed along with the other important groundwater tracing parameters such as, specific conductance and temperature (Duley et al. 1999).

Groundwater Applications

- Time of Travel
- Surface to groundwater communication: presence and paths
- Pollution plume tracing: landfills and spill sites
- Aquifer hydraulics
- Bore hole casing integrity
- Determination of well-drilling fluid circulation time
- Tagging and tracing herbicide migration and dispersion

In Situ Dye Fluorometry Requirements and the 6130 Rhodamine WT Sensor

Until the advent of *in situ* Rhodamine WT measurement systems, dye fluorometry hydrologic studies were performed exclusively by the analysis of multiple samples physically extracted from the water body, at multiple locations, as the dye plume was naturally dispersed. These samples were analyzed either in the field or in the laboratory. To date, the greatest percentage of the analysis (fluorometry) performed for these investigations has employed field fluorometers designed for discrete and pump-through *in vitro* measurement. The mode of operation during one of these investigations is often referred to as "leap-frogging" and alludes to the process whereby teams – at least two – collect samples, perform analysis and then move to a predetermined point or distance downstream of the preceding team. This process is continued downstream until the stream reach under investigation has been sampled and the dye plume has passed.

Over the years, automated sampling systems such as time-actuated dye-sampling boats, and time and flow-actuated peristaltic pump samplers have greatly reduced personnel requirements and labor costs associated with sample collection. However, samples collected by these devices must be retrieved within a short time after a sampling event and still require *in vitro* analysis either in the field or in the laboratory.

Although the aforementioned methods often produce accurate hydrologic data, they are resource intensive: deployment of personnel, vehicles and equipment is necessary throughout the duration of the study, sampling supplies are used in quantity, and discrete or flow-through *in vitro* analysis is performed manually throughout the duration of the study. Furthermore, these methods are significantly vulnerable to human error and other natural phenomenon, and their large personnel component increases risk of injury. The limitations of these methods have become accentuated with the advent and recent employment of *in situ* Rhodamine WT fluorometers. As the demand for the quantity and quality of hydrologic data increases, investigators have begun to search for alternatives, and have indicated that *in situ*, unattended measurement will be the method of choice for future dye fluorometry hydrologic measurements.

Fluorometers, whether designed for discrete or pump-through *in vitro* analysis or *in situ* measurement, operate according to the same principles identified in an earlier section of this document. Given this commonality, the utility of the method and the technology by which it is employed must necessarily come into question as the next step in selecting the appropriate fluorometer.

In response to the need for *in situ* dye fluorometry for hydrologic

studies, such widely recognized companies including, but not limited to, Turner Designs (SCUFA III™), Hobi Labs (Hydro-Scat-2™), Chelsea Instruments (Aqua Tracka™), and YSI, Inc. (Model 6130 sensor) have developed *in situ* fluorometers for the measurement of Rhodamine WT. During the course of research for this document, it became apparent that the system configuration most needed by investigators is that which provides accurate – which includes the measurement of and correction for temperature and conductivity – *in situ* Rhodamine WT measurement for short (≤ 24 hr.) and long deployments (several days), and that can operate autonomously under self-contained power, while storing data internally for field or remote downloads. Generally speaking, this was true for surface water, groundwater and wastewater investigations, but not necessarily for all applications within those areas of study. In addition, it was determined that, at times, it will be necessary to integrate the fluorometer, via SDI-12, with data collection platforms (DCPs); deploy the system *in situ* in 2-inch OD bore-holes; to manually perform surface and vertical profile measurements of Rhodamine WT, and to record these data along with data for other parameters.

The need for parameters in addition to Rhodamine WT appears to be limited (prioritized) first to those absolutely essential for its accurate measurement (temperature and conductivity), and then including those of particular importance, but that are less commonly encountered at problematic levels during most investigations (turbidity and pH). It is important to consider that season-specific and climate-specific conditions, hydraulic features and the extent of perturbation will necessarily shift the relative importance of some of these parameters. A smaller, but significant, portion of investigators — particularly water resource agencies, environmental regulatory agencies, and persons managing wastewater treatment facility performance — need water quality parameters such as DO, pH, chlorophyll, turbidity, ORP and depth or level in addition to Rhodamine (and temperature and conductivity).

At this time, YSI, Inc. offers the only Rhodamine WT fluorometer that can be configured to meet all of the requirements identified previously. At the heart of YSI's system for Rhodamine measurement is the Model 6130 sensor. The 6130 is a fouling-resistant, wiped sensor (Figure 1) designed to seamlessly integrate – using no external interface hardware – with each of YSI's multiparameter sondes that provide an optical port (6820, 6920, 6600 and 600 OMS) and with most sensor configurations (combinations) currently available. Note that the OMS is a small (1.65-inch OD), inexpensive sonde which is ideal for groundwater applications, and for surface and wastewater applications where cost is a consideration and only Rhodamine

WT, temperature, conductivity, and depth or level are required. The 6130 minimizes interference from turbidity, other fluorescent substances such as phytoplankton and, by virtue of its integration with other sensors in YSI multiparameter sondes, its measurements are automatically corrected for the effects of temperature and conductivity.

The need to manually perform surface and vertical profile measurements of Rhodamine WT, and to record these data along with data for other parameters, has been identified. YSI provides a rugged, weatherproof handheld device, the 650 MDS, for viewing data in real-time, and for field viewing and downloading data stored within the sondes. With the 650 MDS the investigator can "look" into the data record without interrupting measurements or deployment instructions, and thus determine if the dye plume has reached or passed the deployment site, while also determining if dye concentrations are within appropriate ranges before leaving the field. The 650 MDS in combination with any YSI sonde with an optical port also facilitates surface and vertical profile measurements that are particularly useful in lakes, reservoirs, bays and deep rivers during reaeration, dispersion, circulation and mixing studies.

Conclusion

To date, the greatest percentage of these investigations are performed using fluorometers designed for *in vitro* and pump-through measurements. Although these methods predominate today, and can produce accurate hydrologic data, they are resource-intensive, significantly vulnerable to human error and other natural phenomenon, and necessitate the field deployment of personnel throughout the duration of the study, which increases risks to safety. The advent and recent employment of *in situ* measurement systems has accentuated the limitations of discrete and *in vitro* pump-through measurement methods for performing these studies. As the demand for the quantity and quality of hydrologic data increases, investigators have begun to search for alternatives, and have indicated that *in situ*, and particularly unattended *in situ* Rhodamine WT measurement, will be the method of choice for future dye fluorometry hydrologic measurements.

Fluorometers, whether designed for discrete or pump-through *in vitro* analysis or *in situ* measurement, operate according to the same principles. Given this commonality, the utility of the method and the technology by which it is employed must necessarily come into question as the next step in selecting the appropriate fluorometer.

The growing need for accurate *in situ* measurement of Rhodamine WT during short (≤ 24 hr) and long deployments (several days), and with a system that can operate autonomously under self-

contained power while storing data internally for field or remote downloads, was identified. Generally speaking, this need held true for surface water, groundwater and wastewater investigations, but not necessarily for all applications within those areas of study. In addition, it was determined that, at times, it will be necessary to integrate the fluorometer, via SDI-12, with data collection platforms (DCPs); to deploy the system *in situ* in 2-inch OD bore-holes; to manually perform surface and vertical profile measurements of Rhodamine WT; and to record these data along with data for other parameters.

YSI, Inc. was found to be the only provider of a Rhodamine WT fluorometer that can be configured to meet all of the requirements identified during this investigation. At the heart of YSI's system for Rhodamine WT measurement is the Model 6130 sensor. The 6130 is a fouling-resistant, wiped sensor designed to seamlessly integrate with YSI's multiparameter sondes and sensor configurations (combinations), including the 1.65-inch OD Optical Monitoring System (OMS). The 6130 minimizes interference from turbidity and other fluorescent substances (i.e., chlorophyll) and, by virtue of its integration with other sensors in YSI sondes, its measurements are automatically corrected for the effects of temperature and conductivity, and may be analyzed in a broad environmental context including, but not limited to, measurements of DO, pH, ORP, chlorophyll, turbidity, depth and level.

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