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**US Army Corps of Engineers**
Waterways Experiment Station

*Aquatic Plant Control Research Program*

# Use of Water Exchange Information to Improve Chemical Control of Eurasian Watermilfoil in Pacific Northwest Rivers

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Prepared for Headquarters, U.S. Army Corps of Engineers
U.S. Army Engineer District, Seattle

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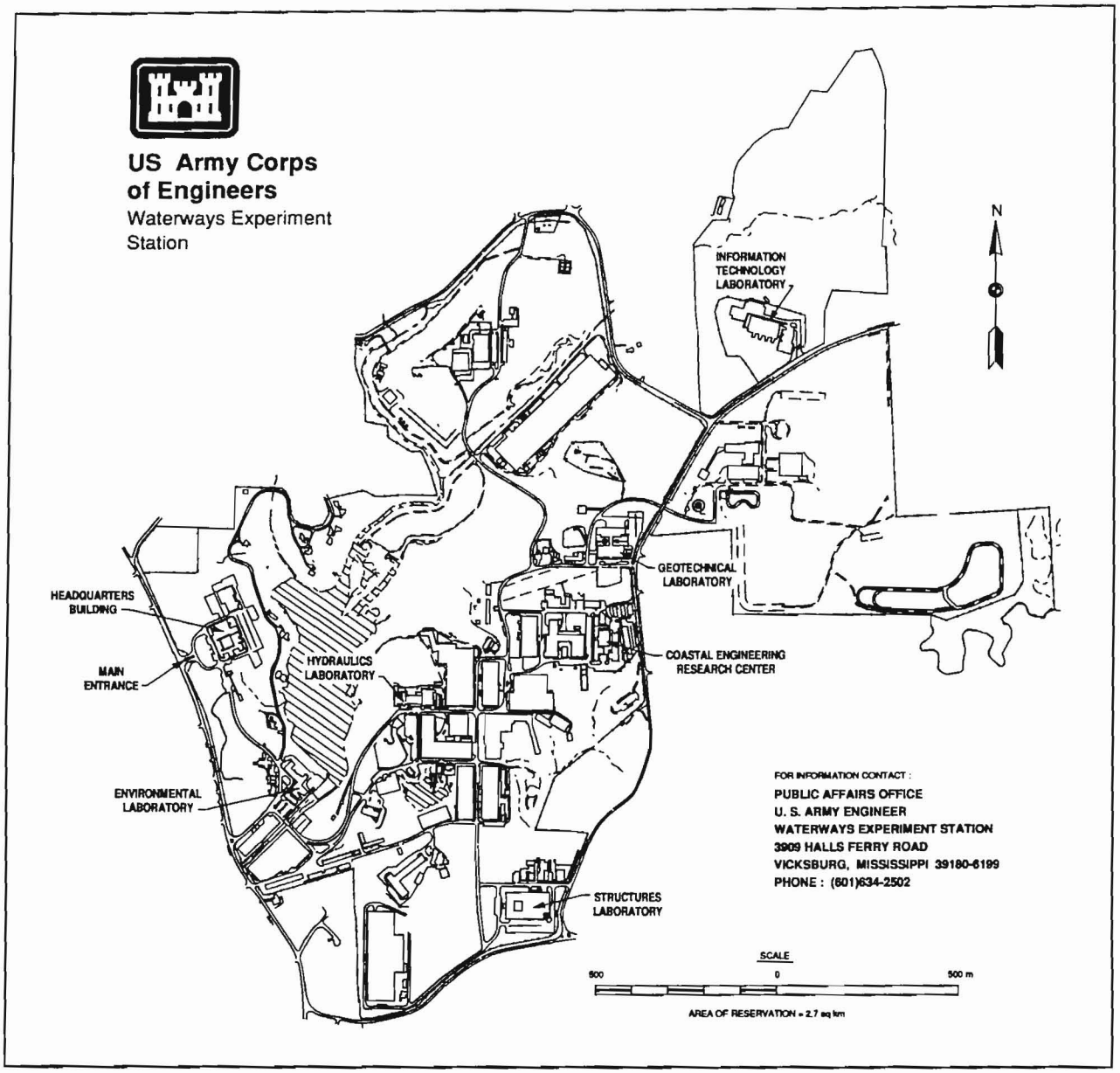


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# Contents

# Preface

The work reported herein was conducted as part of the Aquatic Plant Control Research Program (APCRP), Work Unit 32354. The APCRP is sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), and is assigned to the US Army Engineer Waterways Experiment Station (WES) under the purview of the Environmental Laboratory (EL). Funding was provided under Department of the Army Appropriation No. 96X3122, "Construction General." Additional funding was provided by the US Army Engineer District (USAED), Seattle. The APCRP is managed under the Environmental Resources Research and Assistance Programs (ERRAP), Mr. J. L. Decell, Manager. Mr. Robert C. Gunkel was Assistant Manager, ERRAP, for the APCRP. Technical Monitor during this study was Mr. James Wolcott, HQUSACE.

The principal investigator for the study was Dr. Kurt D. Getsinger, Aquatic Processes and Effects Group (APEG), Ecosystem Research and Simulation Division (ERSD), EL, WES. The study was conducted and the report prepared by Dr. Getsinger, Mr. David Sisneros, US Bureau of Reclamation (BOR), and Mr. E. Glenn Turner, AScI Corporation.

Reviews of the report were provided by Mr. Michael D. Netherland and Ms. Linda S. Nelson, APEG. Technical assistance was provided by Mr. Robert Rawson, USAED, Seattle; Mr. John B. Coyle and personnel, Libby-Albeni Falls Project; Mses. Kathy Hamel and Stefani Boushele, and Mr. Allen Moore, Washington Department of Ecology; Ms. Stephenie Sminks, BOR; Mr. Brian York and Ms. Kimberly Deevers, WES; and Aquatics Unlimited, Inc.

This investigation was performed under the general supervision of Dr. John Harrison, Director, EL; Mr. Donald L. Robey, Chief, ERSD; and Dr. Richard E. Price, Acting Chief, APEG.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

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# 1 Introduction

## Background

The Pend Oreille and Columbia Rivers of eastern Washington have been plagued with Eurasian watermilfoil (*Myriophyllum spicatum* L.) for many years (Rawson 1985; 1987; WATER Environmental Services, Inc. 1986; 1987), and control of these infestations via conventional chemical techniques has proven to be inconsistent (Gibbons and Gibbons 1985). This erratic control is probably associated with a lack of herbicide contact time in the treatment area. Recent work has indicated that water movement can play a major role in the dispersion of herbicides from treated plots, as well as in the distribution of herbicides in the water column (Getsinger, Hall, and Fox 1990; Getsinger, Green, and Westerdahl 1990; Getsinger et al. 1991; Fox, Haller, and Getsinger 1991). If water exchange decreases the contact time or dilutes the concentration of a herbicide around the target plant, inconsistent control can result. A better understanding of water movement within submersed plant stands in the dynamic environments of North Pacific rivers will serve to define the limits of herbicide use for controlling Eurasian watermilfoil in those systems.

In 1988, a series of small-scale dye studies in the Pend Oreille River showed that the fluorescent dye, rhodamine WT, could be used to estimate water movement within submersed plant stands (Getsinger, Green, and Westerdahl 1990). Furthermore, water exchange information derived from those studies and results from herbicide concentration/exposure time experiments (Green and Westerdahl 1990; Netherland, Green, and Getsinger 1991; Netherland and Getsinger 1992), suggested that chemical control of Eurasian watermilfoil in selected areas of the Pend Oreille River was possible. As a continuation of the 1988 work, dye studies were recently conducted in submersed plant stands in the Pend Oreille and Columbia Rivers. These studies consisted of two types of dye treatments. The first type was designed to simulate large-scale, conventional herbicide treatment in which the selected plot was treated with a liquid formulation in a single application. This type of treatment also served to verify the results of the 1988 dye studies. The second type of dye treatment involved the use of slow, or controlled-release technology in which chemicals are released at a continuous, low rate from an inert matrix formulation.

Slow- or controlled-release, technology provides several advantages over conventional application techniques, especially in flowing water. First, the longevity of herbicide exposure is increased, providing adequate concentration/exposure time relationships for improved control, thus reducing repeated treatments; second, lower concentrations of herbicides are delivered, which are less likely to affect nontarget organisms and desirable vegetation; and third, slow-release devices can be placed in specific target areas or manipulated to optimize effective coverage (Trimnell et al. 1982).

The concept of using slow-release systems to chemically control aquatic pests is not new. Early development of slow-release matrices for controlling aquatic insects and mollusks concentrated on using carrier materials such as cement briquettes (Evans and Fink 1960, Barnes and Webb 1968), rubber (Cardarelli, Senderling, and Wuerzer 1967; Schultz and Webb 1969), and plastics (Whitlaw and Evans 1968, Nelson et al. 1970). Also, several types of slow-release herbicide matrices have been evaluated during the past two decades (Steward and Nelson 1972; Harris, Norris, and Post 1973; Cardarelli and Raddick 1983; Connick et al. 1984).

In the late 1970's, the US Army Engineer Waterways Experiment Station (WES) evaluated three slow-release herbicide formulations in the laboratory and the field. These formulations consisted of: (a) 2,4-D (2,4-dichlorophenoxy acid) in kraft-lignin pellets; (b) an acrylic polymer, glycidyl methacrylate (Poly GMA), plus 2,4-D impregnated in clay pellets; and (c) a natural rubber elastomer combined with 2,4-D butoxyethanol (14-ACE-B). Subsequent testing revealed that herbicide release rates from the kraft-lignin and Poly GMA formulations were relatively constant, providing a slow release of 2,4-D for 2 to 6 months (Van and Steward 1982, 1983). However, the 14-ACE-B formulation was ineffective in governing the slow release of 2,4-D, with most of the herbicide released in 2 to 3 days (Getsinger and Westerdahl 1984). In the mid 1980's, a fibrous slow-release system consisting of polycaprolactone (PCL) was developed by WES (Dunn et al. 1988) for delivering the herbicides diquat (6,7-dihydrodipyrido[1,2-∝2',1'-c]pyrazinediium ion) and fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1H)-pyridinone). This PCL matrix was field-tested with fluridone in Texas, Florida, and Washington (Westerdahl, Hall, and Getsinger 1984).

Problems associated with the development of previous slow-release formulations included scale-up procedures to produce large quantities of material, inconsistent release profiles, and the reluctance of industry to change existing commericial herbicide formulations. However, the recent information on herbicide concentration/exposure time relationships and water-exchange in submersed plant stands indicates that slow-release technology may dramatically improve control in flowing water systems.

As previously mentioned, materials such as cement, rubber, and plastics were used as inert components in the early development of slow-release matrices. These materials were generally nonbiodegradable and, there-

fore, were not considered good prospects for commercial use. Current development of slow-release materials for aquatic pest control, however, has produced matrices that will readily degrade in the environment. For example, a new technology using a gypsum-based matrix has emerged as a leading slow-release technology in aquatic insect control. This product, incorporated with the active ingredient methoprene, has been successfully licensed and marketed by Zoecon Corporation as a mosquito larvicide (Genereux and Genereux 1985). The proven slow-release characteristics and environmental compatibility of the gypsum matrix have made this product an excellent candidate for testing with aquatic herbicides.

## Objectives

The objectives of these dye studies were to: (a) characterize water exchange in large stands of Eurasian watermilfoil in the Pend Oreille and Columbia Rivers; (b) compare results of these studies with results from previous, small-scale Pend Oreille River water-exchange studies; (c) evaluate potential herbicide release rates from a slow-release matrix device in the Pend Oreille River; and (d) use this combined information (in conjunction with herbicide concentration/exposure time data) to recommend field evaluation of herbicides for controlling Eurasian watermilfoil in the rivers of the Pacific Northwest.

# 2 Materials and Methods

## Conventional Dye Applications

In August 1990, rhodamine WT dye was applied to three 4-ha (10-acre) Eurasian watermilfoil-infested plots on the Pend Oreille and Columbia Rivers, Washington (Figure 1). The first Pend Oreille River treatment (Plot PR-61) was located approximately 0.5 km upstream from river mile 61, between the western shore of the river and a narrow island directly to the east. The depth in Plot PR-61 ranged from 1.1 to 2.2 m, with a mean depth of 1.7 m. The second Pend Oreille treatment (Plot PR-LCB) was situated within Lost Creek Bay, approximately 0.3 km downstream and northwest of river mile 48. The depth in Plot PR-LCB ranged from 1.3 to 2.0 m, with a mean depth of 1.8 m. Eurasian watermilfoil was the dominant submersed macrophyte in both plots (estimated cover = 90 percent), and shoots were at, or near, the surface at the time of dye application.

Discharge rates measured from the US Army Engineer Albeni Falls Dam, located approximately 45 to 70 river-km upstream from the Pend Oreille plots, ranged from 283 to 436 $m^3$/sec (10,000 to 15,400 cfs) during the study. These rates are typical August discharges for Albeni Falls Dam. Mean water flow, measured with a Marsh McBirney digital flow meter (Model No. 201), was 2.0 cm/sec in Plot PR-61 and < 0.3 cm/sec in Plot PR-LCB.

The Columbia River treatment (Plot CR-DP) was located approximately 20 km upstream from the Chelan County Public Utility District Rocky Reach Dam. This plot was established approximately 0.5 km downstream from the southern boundary of Daroga Park, near the eastern shore of the river. The depth in Plot CR-DP ranged from 1.0 to 1.9 m, with a mean depth of 1.5 m. Eurasian watermilfoil was the dominant submersed macrophyte in the plot (estimated cover = 95 percent), and shoots were at, or near, the surface at the time of dye application.

Rhodamine WT was tank-mixed with river water and applied by airboat using a pressurized, diaphragm pump fitted with short (0.5-m), stern-mounted hoses to achieve a concentration of 10 µg/L (ppb) dye throughout the water volume of each plot. Rhodamine WT dye is approved for use in

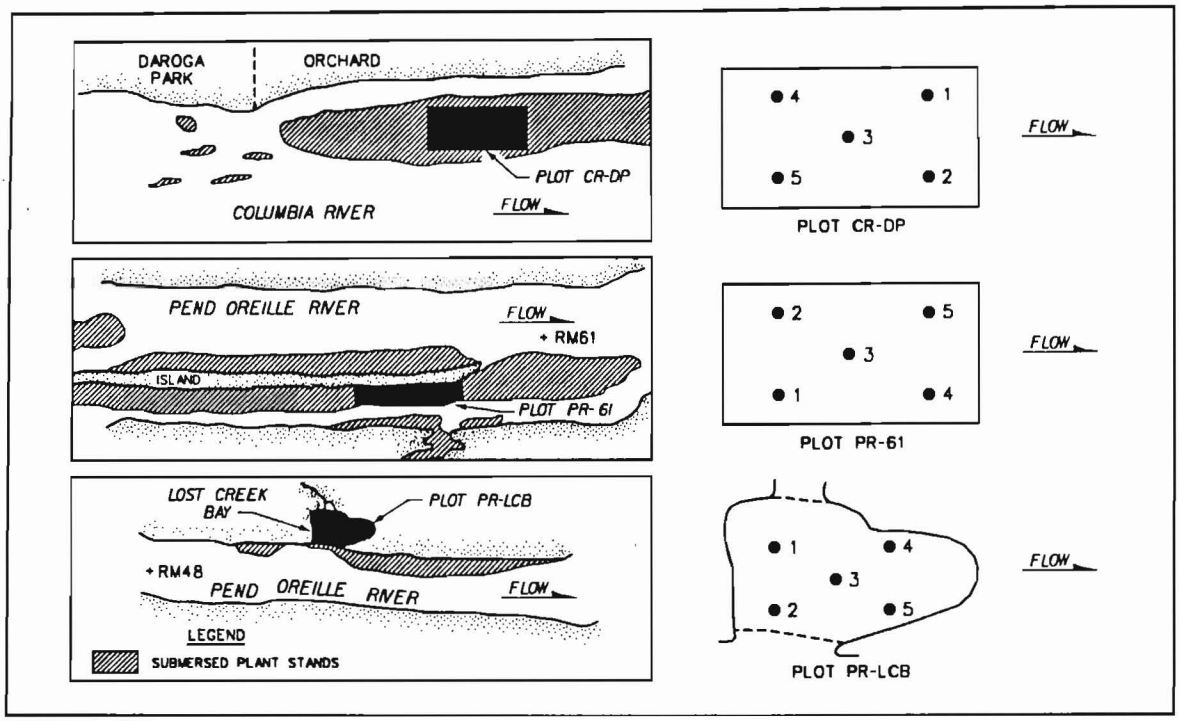


Figure 1. Dye treatments on Pend Oreille (Plots PR-61 and PR-LCB) and Columbia Rivers, Washington, 1990

potable water by the US Environmental Protection Agency (EPA) at concentrations up to 10 µg/L, and is routinely used for water tracing and exchange studies (Johnson 1984; Kilpatrick and Wilson 1989). In addition, Rhodamine WT has been shown to be resistant to most processes that could lead to reduced dye concentrations over a period of up to 2 weeks, such as photodegradation, biodegradation, adsorption to sediment, and uptake by submersed plants (Smart and Smith 1976; Smart and Laidlaw 1977; Fox, Haller, and Getsinger 1991; Turner, Netherland, and Getsinger 1991).

Five sampling stations were established in each plot (Figure 1), and dye concentrations were measured simultaneously at 25-cm intervals from surface to bottom. Dye was monitored using a calibrated Turner Design Model 10-005 field fluorometer fitted with a high-volume, continuous-flow cuvette system, and a thermocouple thermometer to allow for corrected dye readings (Smart and Laidlaw 1977). Plot PR-61 was monitored for 12 hr posttreatment, Plot PR-LCB for 120 hr posttreatment, and Plot CR-DP for 30 hr posttreatment. Dye half-lives within each plot were calculated by regressing the natural logarithms of dye concentrations (from individual, selected, and all stations within the plots) over eight sampling time intervals.

# Slow Release Matrix Device (SRMD) Dye Applications

## SRMD Design

Thirty-three SRMDs were obtained from Accugran, Inc., Minneapolis, MN. These prototype devices consisted of a plastic housing and a matrix core of calcium sulfate (gypsum), as depicted in Figure 2. The plastic housing was constructed from 0.48-cm thick, polyvinyl chloride pipe (Schedule 40) that was 7.6 cm wide by 31.1 cm in diameter. Three 0.56-cm eye screws were attached to the housing at selected locations for supporting and anchoring the SRMD at various depths in the water column. In addition, 0.56-cm hardware screen was placed over both sides of the SRMD to prevent the matrix material from escaping from the housing following installation. The patented matrix (see patent information, Appendix A) was composed of gypsum containing 30 percent by weight of a 40-percent rhodamine WT dye. Average weight of each SRMD (matrix plus housing) was 7.4 kg (±0.2 kg SD). Based on estimated water exchange rates during August on the Pend Oreille River, the SRMDs were designed to provide a dye concentration of 10 µg/L in the water column over a 14-day time interval.

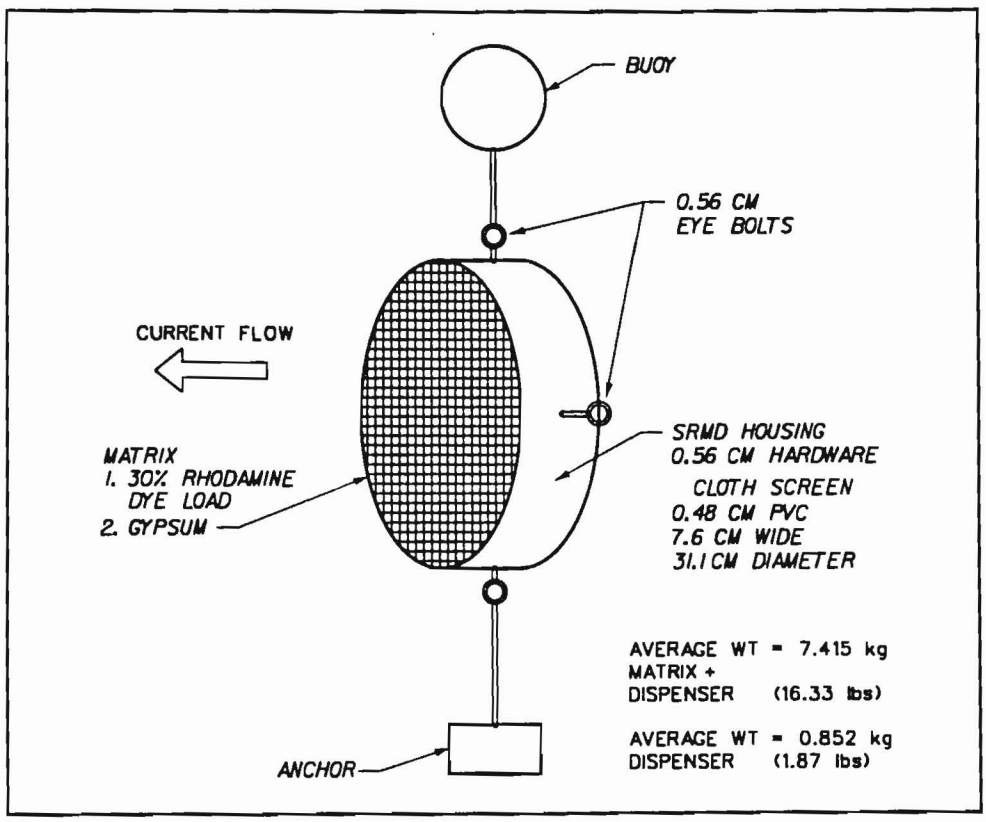


Figure 2. Schematic of SRMD

## Plot description

Two treatment areas (Plots 1 and 2) were established in the Pend Oreille River near river mile 61 (Figure 3). Eurasian watermilfoil comprised an estimated 90 percent, or more, of the submersed plant coverage within the plots, and plant shoots were within 15 cm of the surface during the course of the experiment. River discharges, measured at Albeni Falls Dam, ranged from 286 to 447 $m^3$/sec (10,100 to 15,800 cfs) during the 6 through 17 August 1990 study period (Appendix B, Figure B1).

**Plot 1.** This mid-channel plot was 0.4 ha in size, with sampling sites (SS1 through SS4) established in the center of each plot quadrant (Figure 4). Plot depth ranged from 0.8 to 2.5 m, with a mean depth of 1.8 m. Two additional sampling sites were located in deeper water, 60 m downstream of the northern edge of the plot (SS5) and 30 m from the western edge of the plot (SS6). Depths for sampling sites SS5 and SS6 were 3.6 and 3.0 m, respectively.

Duplicate flow rates were taken prior to deployment of the SRMDs at sampling sites within the plot and at the corners of the plot at mid-depth using the digital flowmeter. Flow rates ranged from < 1.5 to 6.1 cm/sec, with an average flow rate of 3.0 cm/sec. The highest flow rate (6.1 cm/sec) was measured at the southeast corner of the plot, located adjacent to

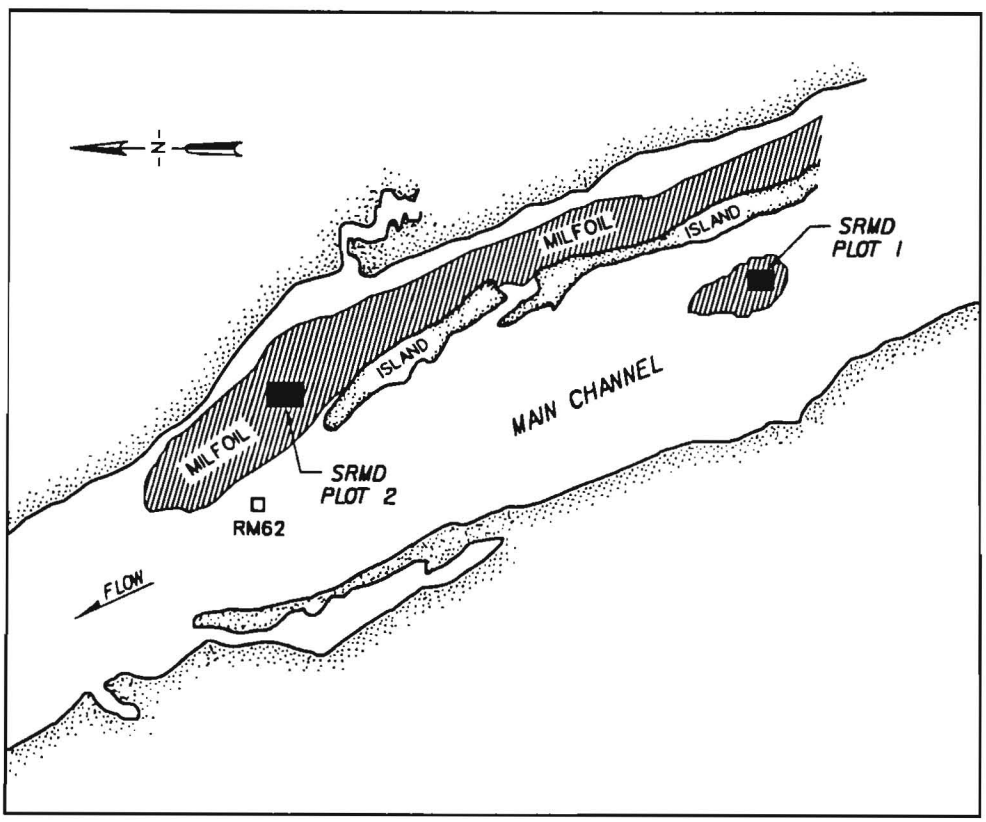


Figure 3. SRMD treatment plots on the Pend Oreille River, Washington, 1990

emergent vegetation (*Scirpus* spp.), which probably influenced the water currents denoted by arrows in Figure 4.

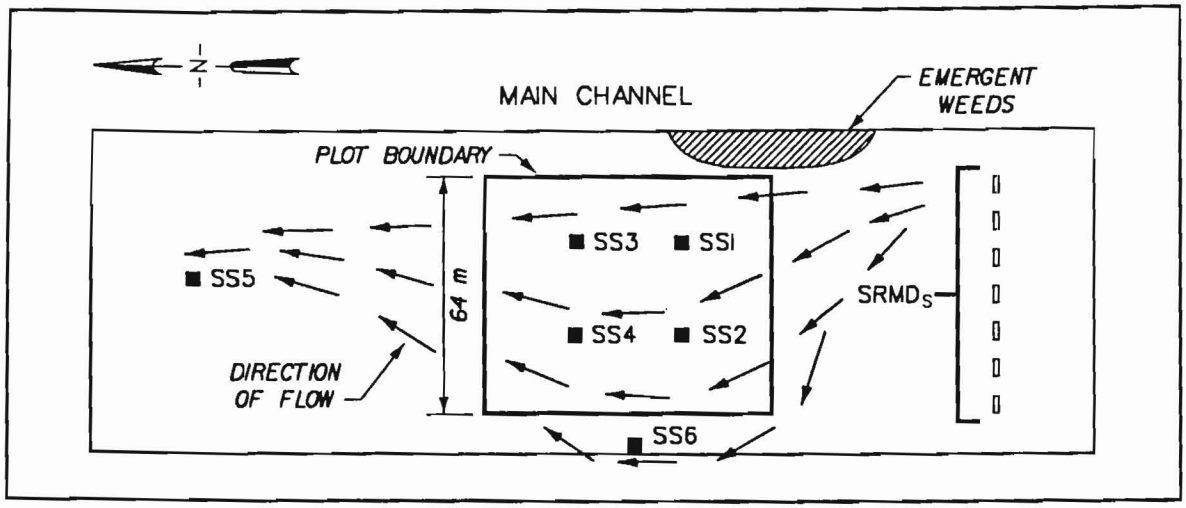


Figure 4. Schematic of SRMD Plot 1 on the Pend Oreille River, Washington, 1990, depicting location of SRMDs and sampling stations (SS1-SS6)

On day 0, 13 SRMDs were suspended (at mid-depth) approximately 17 m upstream of the southern edge of the plot, and spaced at 6-m intervals (Figure 4). Four additional SRMDs were deployed in the same location as the original thirteen, two on day 3 and two on day 4. Visual inspection of each SRMD was conducted on a daily basis to determine matrix consistency and longevity. Dye concentrations were measured at 30-cm intervals from the water surface to the bottom using a calibrated fluorometer (as previously described in the conventional dye application section) at 6 and 24 hr, and daily for 10 days after deployment (DAD).

**Plot 2.** Plot 2, 1.1 ha in size, was isolated from the main river channel by a narrow island, with five sampling sites (SS1 through SS5) established within the plot (Figure 5). In addition, sampling site SS6 was located 90 m downstream from the northern edge of the plot. Plot depth ranged from 1.8 to 2.4 m, with an average depth of 1.8 m. Duplicate flow rates were taken (mid-depth) at sampling sites within the plot and at the corners of the plot. Flow rates ranged from < 0.3 to 6.1 cm/sec, with a mean rate of 2.1 cm/sec.

On day 0, thirteen SRMDs were suspended upstream of the plot (as described for Plot 1), followed by deployment of one SRMD on day 2 and two SRMDs on day 3. Visual inspections of SRMDs were conducted and dye concentrations were measured (as described for Plot 1) on a daily basis for 9 DAD.

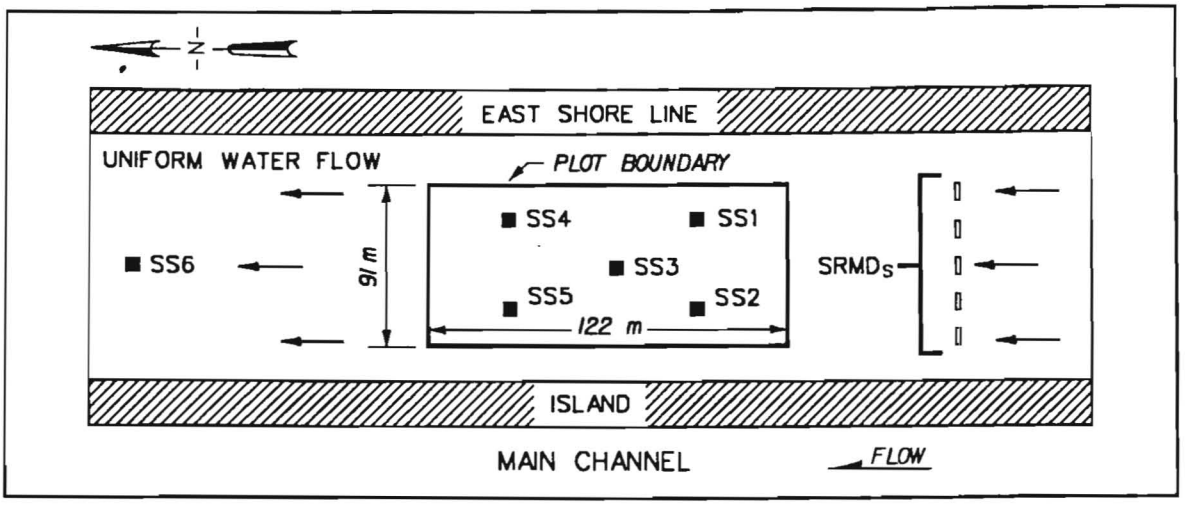


Figure 5. Schematic of SRMD Plot 2 on the Pend Oreille River, Washington, 1990, depicting location of SRMDs and sampling stations (SS1-SS6)

# 3 Results and Discussion

## Conventional Dye Applications

### Pend Oreille River plots

**Plot PR-61.** Dye half-lives and regression equations for Plot PR-61 are presented in Table 1. Mean dye half-life (calculated with data from all sampling stations) for this riverine plot was 8.8 hr. The mean dye half-lives for Stations 1 + 2 (6.3 hr) were shorter than half-lives for Stations 4 + 5 (16.8 hr). These results were not unexpected, since Stations 1 and 2 were located upstream of Stations 4 and 5. Dye-treated water in the upstream portion of the plot flowed downstream and increased the dye retention time in that portion of the plot. The previously noted conservative nature of rhodamine WT demonstrates that dye half-lives reported for these studies would provide accurate information concerning water exchange characteristics in the plots.

Dye was concentrated in the upper 100 cm of the water column in the plot, and generally low levels of dye were measured in the bottom waters (Appendix B, Figures B2 through B9). Undoubtedly, lateral water flow, water temperature, and the use of a shallow, subsurface application technique contributed to the stratification of dye in the water column. In the 1988 Pend Oreille dye studies (Getsinger, Green, and Westerdahl 1990), two conventional liquid application techniques (shallow, subsurface injection versus weighted-hose, deep injection) were evaluated for dye distribution patterns. Results from this comparison showed that the deep injection technique could enhance the water-column distribution of a liquid formulation; however, if plants were at or near the surface, weighted hoses employed in the deep injection technique were buoyed to the surface by the plant biomass during the application. Under those conditions there was little distribution advantage provided by the long, weighted hoses. Moreover, the weighted hoses readily entangled with vegetation dragging large, heavy mats of plants beneath (or behind) the application boat. Since plants were at or near the surface throughout Plot PR-61, a shallow, subsurface application technique was used.

**Table 1**
**Half-lives and Regression Equations for Dissipation of Dye from Plots Treated with Conventional Application Techniques in the Pend Oreille and Columbia Rivers, Washington, August 1990**

| Plot | Station | Regression Line $C_t = C_o - a(t)$ | $r^2$ | Half-life (hr) |
|---|---|---|---|---|
| | | **Pend Oreille** | | |
| PR-61 | 1-5 | y = 2.44 - 0.078t | 0.99 | 8.8 |
| | 1+2 | y = 2.26 - 0.109t | 0.88 | 6.3 |
| | 4+5 | y = 2.46 - 0.041t | 0.82 | 16.8 |
| PR-LCB | 1-5 | y = 3.24 - 0.019t | 0.97 | 36.3 |
| | 1+2 | y = 3.29 - 0.019t | 0.86 | 35.4 |
| | 4+5 | y = 3.22 - 0.019t | 0.74 | 37.0 |
| | | **Columbia** | | |
| CR-DP | 1-5 | y = 2.09 - 0.057t | 0.80 | 12.2 |
| | 1+2 | y = 2.50 - 0.045t | 0.79 | 15.4 |
| | 4+5 | y = 0.28 - 0.069t | 0.34 | 10.0 |

Note: $C_1$ = dye concentration at time t (inverse ln y = estimated [dye]).
$C_2$ = dye concentration at time 0.
a = slope of regression line (dissipation factor).

The 8.8-hr half-life in Plot PR-61 was over four times longer than the mean dye half-life (2.0 hr) following treatment of a different Pend Oreille riverine plot in August 1988 (Getsinger, Green, and Westerdahl 1990). It should be noted that this dye dissipation disparity occurred even though the river discharge rate of August 1990 (283-436 $m^3$/sec) was over twice that of August 1988 (113-170 $m^3$/sec). The 4-ha Plot PR-61 was considerably larger than the 0.5-ha 1988 plot, and was situated in a more protected location with respect to the main river channel (i.e., between the shore and a narrow island) than was the 1988 plot (which was located adjacent to the main channel). Apparently, these two factors counteracted the greater river discharge in 1990, contributing to slower dissipation of the dye in Plot PR-61.

**Plot PR-LCB**. Mean dye half-life (calculated with data from all stations) was 36.3 hr in this protected, cove plot (Table 1). Mean half-lives for the northern portion (Stations 1 and 2) and the southern portion (Stations 4 and 5) of the plot were similar, 35.4 and 37.0 hr, respectively. Dye was more evenly distributed throughout the water column in this plot than in Plot PR-61 (Appendix B, Figures B10 through B16). Enhanced water-column mixing and similar dye half-lives at different stations would be expected to occur in the more quiescent waters of Lost Creek Bay, versus the more hydrodynamic conditions of Plot PR-61.

As was the case for Plot PR-61, the half-life in the 4-ha Plot PR-LCB (36.3 hr) was considerably longer than the half-life from a 0.4-ha plot (16.0 hr) in Lost Creek Bay treated with dye in August 1988 (Getsinger, Green, and Westerdahl 1990). The larger size of the 1990 cove plot probably contributed to a longer dye half-life. In addition, the 1990 river discharge created a higher river stage, increasing the water volume of Lost Creek Bay, compared to 1988. This increased volume, and the potential reconfiguration of sand bars near the mouth of the bay, could have prolonged the bay's flushing rate and increased the half-life of the dye.

## Columbia River plot

**Plot CR-DP**. Dye half-lives and regression equations for Plot CR-DP are presented in Table 1. Mean half-life (calculated with data from all stations) for this plot was 12.2 hr. As in the Pend Oreille riverine plot (Plot PR-61), dye dissipation was more rapid (half-life = 10.0 hr) in the upstream portion (Stations 4 + 5) versus the downstream portion (Stations 1 + 2; half-life = 15.4 hr) of Plot CR-DP. Water flow in this stretch of the river fluctuated slightly during the dye application period. Within minutes after initiation of dye treatment, flow velocities increased more than 3 cm/sec in a downstream direction (for approximately 45 min) and then returned to a velocity less than 1 cm/sec. These flow rate variations were caused by the electric power-generating operations of the Rocky Reach Dam, some 22 km downstream from the plot. The flow fluctuations impacted the dispersion of dye in the upstream portion of the plot to a greater degree than in the downstream portion. This may have contributed to the higher variability in dye concentrations measured at Stations 4 and 5, and the low regression coefficient ($r^2 = 0.34$) for the calculated half-life in the upstream portion of the plot.

Highest dye concentrations occurred in the upper 75 cm of the water column in all stations, and vertical distribution of the dye was more complete in downstream stations (Appendix B, Figures B17 through B22). Following the flow fluctuation period mentioned above, dye concentrations remained relatively constant (or decreased gradually) at most stations through 8 hr posttreatment. Since this period of slow water exchange could be extremely critical for enhancing herbicide contact time (and therefore efficacy), future chemical treatment programs should be closely coordinated with the operating schedules of associated dams.

## SRMD Dye Applications

### SRMD Plot 1

Mean daily dye measurements for internal sampling sites (SS1 + SS2 and SS3 + SS4) are plotted in Figure 6. Dye measurements for external sampling sites (SS5 and SS6) were not averaged and are presented in Figure 7. There was a large release of dye (> 100 µg/L and up to 130 µg/L) at all internal sampling sites 1 to 2 days following the deployment of the SRMDs. This early outburst of dye was followed by stepwise declines of dye for a period of up to 10 DAD. Some of the variability in dye release might be attributed to the fluctuation in river flows during the study. As shown in Appendix B (Figure B1), river discharge rates were lowest at 1 and 2, and 8 through 11 DAD.

In most cases, the target concentration of 10 µg/L dye in the water column was met or exceeded. Higher dye concentrations were found at lower depths, especially at 1.2, 1.5, and 1.8 m, whereas dye concentrations measured at the 0.3-, 0.6-, and 0.9-m depths more closely approximated the target dye concentration. Dye concentrations at the internal sampling sites were still near 10 µg/L at 7 DAD.

Dye concentrations (1 to 17 µg/L) were found approximately 60 m from the downstream edge of the plot (SS5) for up to 10 days, and some lateral movement of dye was measured to the west of the plot (SS6) up to 3 DAD. However, concentration in these external sampling stations declined during the 4- to 10-DAD period. Dye levels at SS6 (west of the plot) were well below 1 µg/L by 3 DAD and levels at SS5 (downstream from the plot) were between 1 and 2 µg/L by 8 DAD.

Channeling of dye was visible as distinct color bands in the upstream area of the plot as dye was released from the SRMDs. Channeling was not evident towards the downstream portion of the plot. The SRMDs deployed upstream and southeast of the plot (and adjacent to the emergent vegetation) on 3 and 4 DAD improved the dye coverage in the eastern portion of the plot.

### SRMD Plot 2

Dye concentrations measured at internal sampling sites SS1 + SS2 and SS4 + SS5 were averaged and plotted over 9 days (Figure 8). Dye was measured at internal sampling site SS3 and external sampling site SS6, and dye concentrations were not averaged at those sites (Figure 9). Similar to Plot 1, there was a large, initial release of dye measured (up to 82 µg/L) at all internal sampling sites 1 day following deployment of the SRMDs. Dye levels decreased to more moderate levels by 3 DAD. Again, some of the variability in dye concentrations observed during the study might have been related to fluctuating river flows.

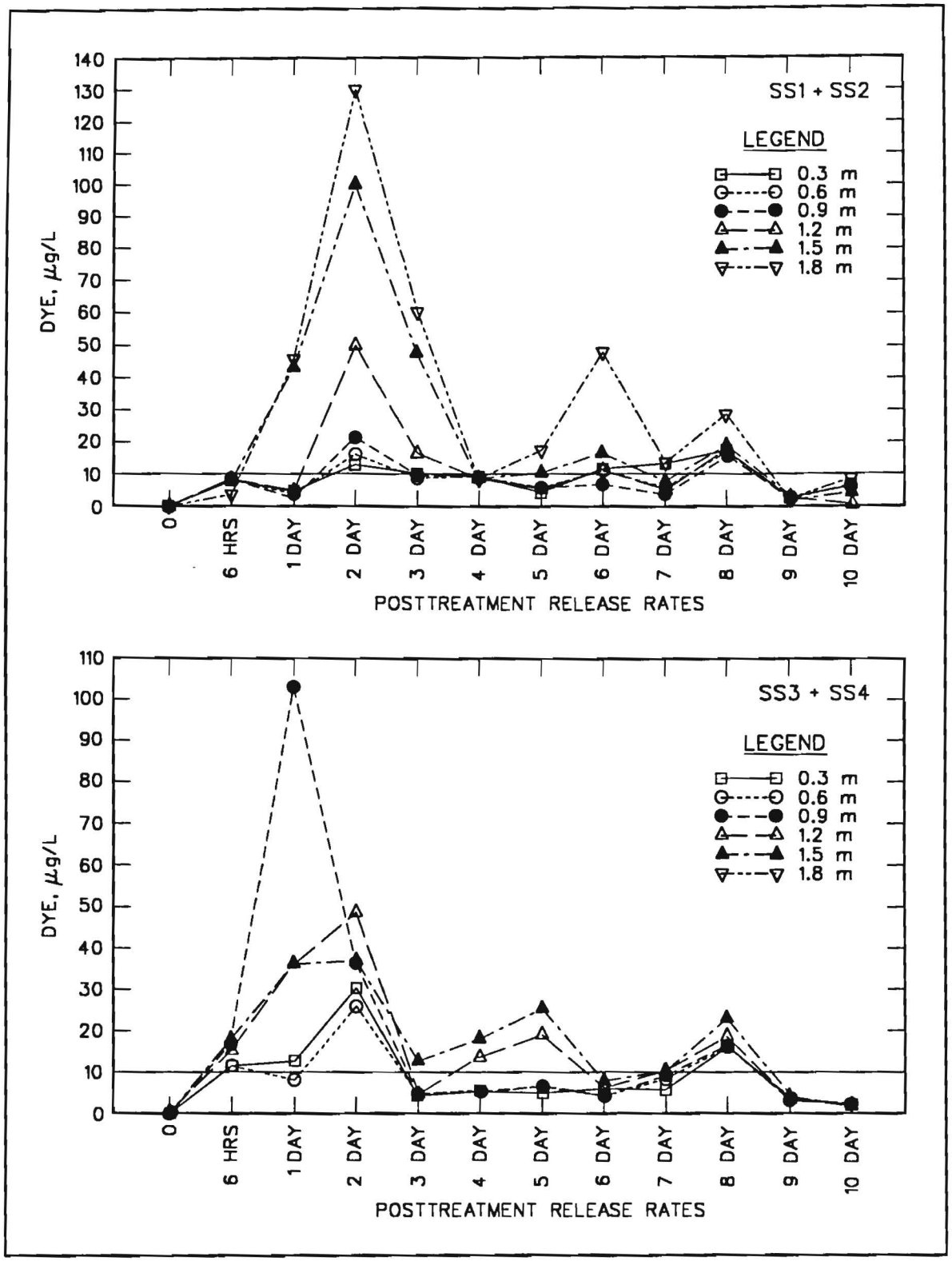


Figure 6. Dye concentration (µg/L) at sampling stations SS1-SS4 in SRMD Plot 1, Pend Oreille River, Washington, 1990

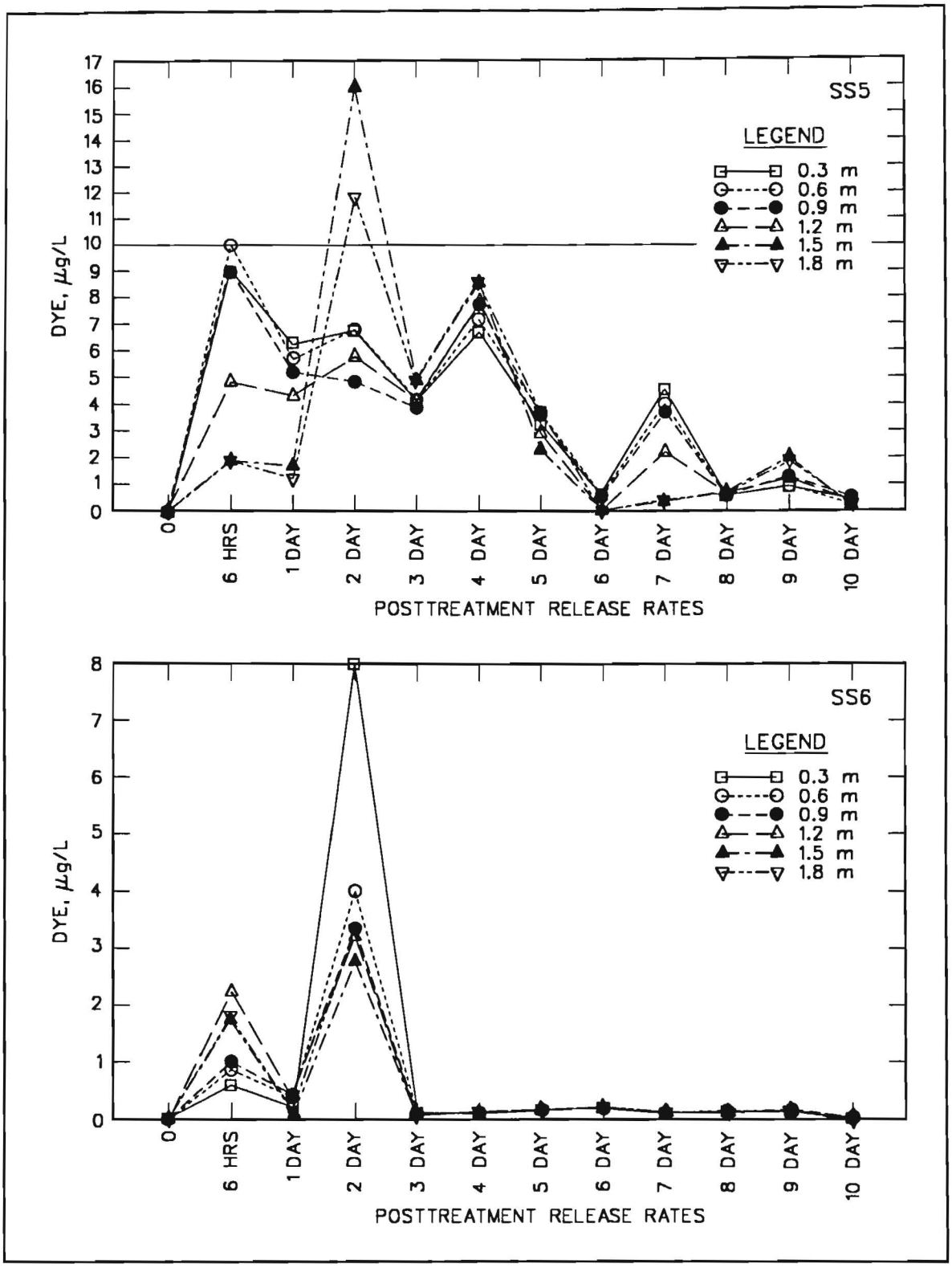


Figure 7. Dye concentration (µg/L) at sampling stations SS5 and SS6 outside of SRMD Plot 1, Pend Oreille River, Washington, 1990

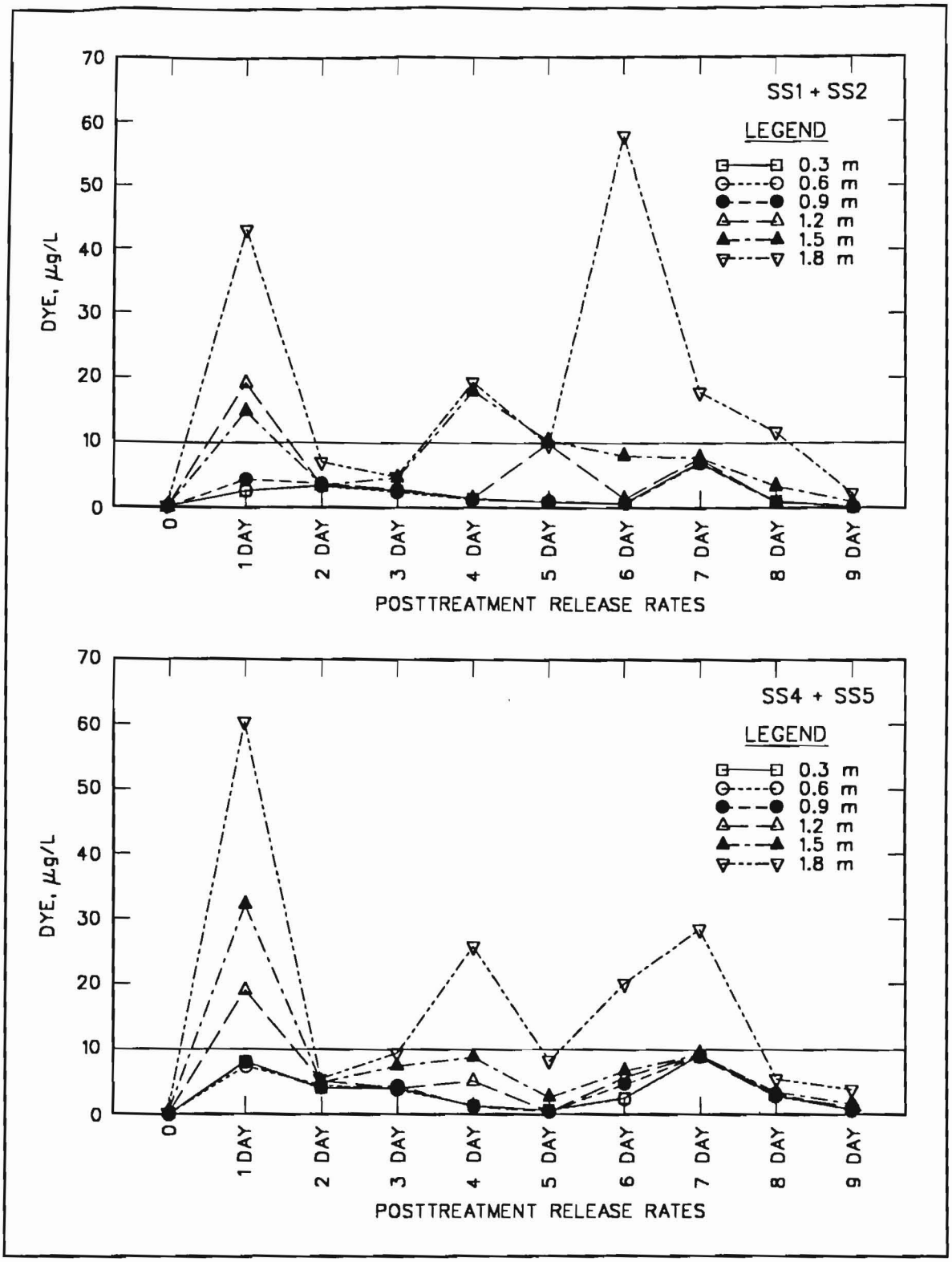


Figure 8. Dye concentration (µg/L) at sampling stations SS1, SS2, SS4, and SS5 in SRMD Plot 2, Pend Oreille River, Washington, 1990

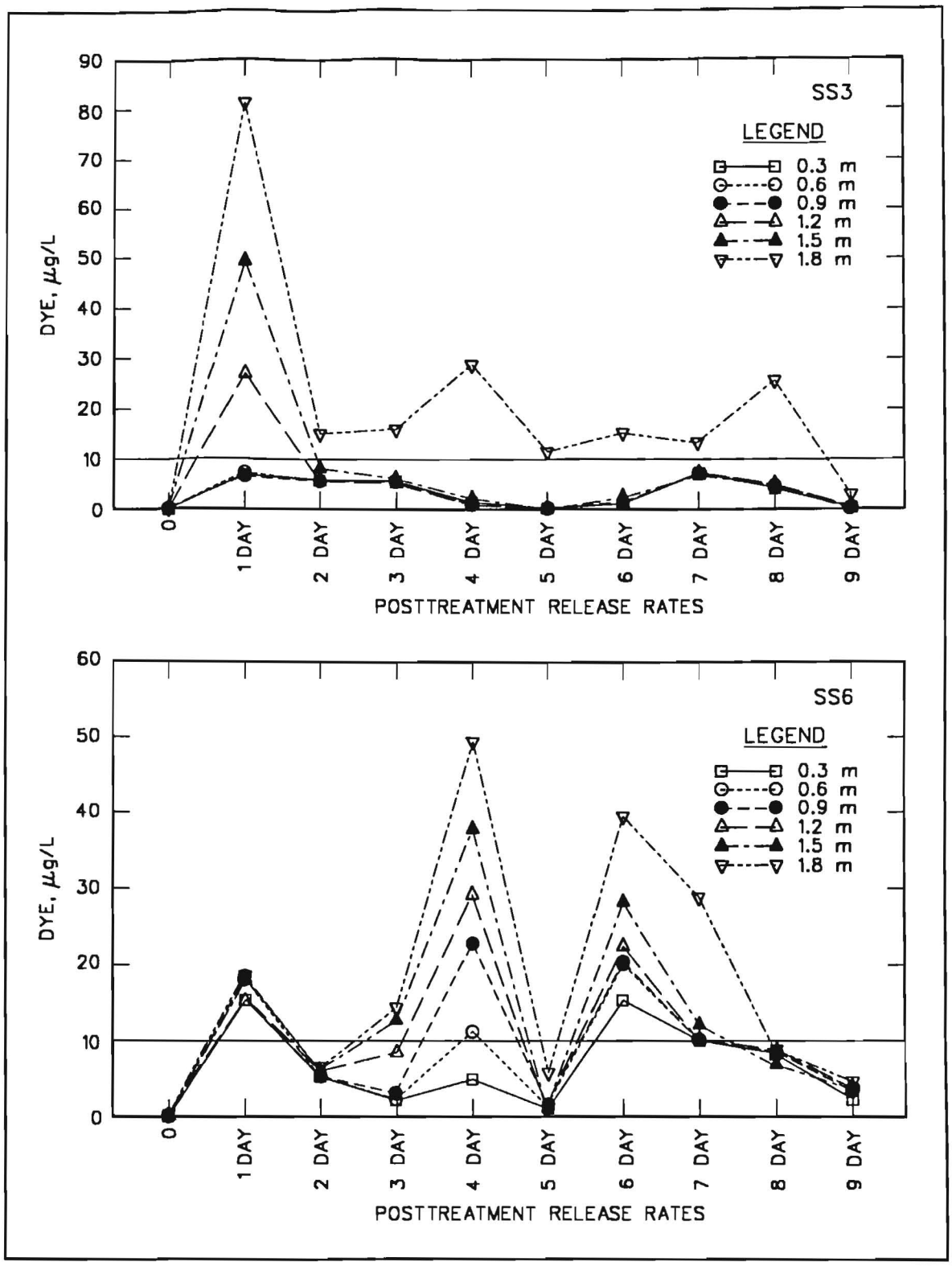


Figure 9. Dye concentration (µg/L) at sampling stations SS3 (interior) and SS6 (downstream) in SRMD Plot 2, Pend Oreille River, Washington, 1990

At the majority of sampling times, higher dye concentrations were in the water column at the 1.2-, 1.5-, and 1.8-m depths. These dye values met, or exceeded, the target dye concentration of 10 µg/L. Dye levels at sampling depths of 0.3, 0.6, and 0.9 m more closely approximated the target dye concentration (10 µg/L) than did dye levels at greater depths. Dye values were near 1 µg/L by 9 DAD at all sampling sites. Dye concentrations in the external, downstream sampling site (SS6) followed patterns similar to those found in the internal sampling sites.

### SRMD longevity

Although designed for a life of 14 days, longevity of SRMDs ranged from 3 to 8 DAD (Table 2). The large amount of water required to make the gypsum/dye matrix used in these studies caused the SRMDs to be somewhat soft in texture (as opposed to the hardened gypsum/insecticide matrix). Daily visual inspections revealed that the soft matrix material was eroding away from its external housing at a rate faster than expected. This hardness and erosion problem is not anticipated in the construction of gypsum/herbicide SRMDs. The ratio of herbicide active ingredient to inert matrix will be much lower than that of the dye to inert matrix ratio, and this factor should increase the longevity of the SRMD. In addition, technology being developed by Accugran, Inc. will allow encapsulation of formulated products that may contain only 40 to 50 percent active ingredient.

**Table 2**
**Longevity of Slow-Release Matrix Devices in the Pend Oreille River, Washington, August 1990**

| Plot 1 | | Plot 2 | |
|---|---|---|---|
| No. of SRMDs | Longevity | No. of SRMDs | Longevity |
| 1 | 3 days | 1 | 4 days |
| 5 | 4 days | 3 | 5 days |
| 5 | 5 days | 5 | 6 days |
| 5 | 6 days | 3 | 7 days |
| 1 | 8 days | 4 | 8 days |

## Potential Use of Herbicides

A summary of herbicide concentration/exposure time (CET) relationships for Eurasian watermilfoil (determined in laboratory evaluations at WES) is presented in Table 3. Results from these studies showed that concentrations approaching the maximum label rates for endothall (7-oxabicyclo[2.2.1] heptane-2,3-dicarboxylic acid), triclopyr ([(3,5,6-trichloro-2-pyridinyl)oxy]-

acetic acid), and 2,4-D were capable of providing 85 to 100 percent control when the target plant was exposed for 8 to 12, 18, and 24 to 36 hr, respectively.

**Table 3**
**Estimated Concentration/Exposure Time Relationships for Controlling Eurasian Watermilfoil Using the Herbicides Endothall, 2,4-D, and Triclopyr**

| Herbicide | Concentration (mg/L) | Exposure Time (hr) for 85-100% Control | Source |
|---|---|---|---|
| Endothall | 0.5<br>1.0<br>2.0<br>3.0<br>4.0<br>5.0[1] | 48<br>36<br>24<br>18<br>12<br>8 | Netherland, Green, and Getsinger 1991 |
| 2,4-D | 0.5<br>1.0<br>1.5<br>2.0[1] | 72<br>48<br>36<br>24 | Green and Westerdahl 1990 |
| Triclopyr | 0.5<br>1.0<br>1.5<br>2.0<br>2.5[1] | 48<br>36<br>24<br>18<br>18 | Netherland and Getsinger 1992 |

[1] Maximum label rate.

When these herbicide CET relationships are compared with the water-exchange information obtained from the conventional dye applications, it is apparent that endothall should provide the most effective control in exposed riverine locations (e.g., Plots PR-61 and CR-DP), while all three herbicides should provide acceptable control in protected cove sites (e.g., Plot PR-LCB). Gibbons and Gibbons (1985) reported good initial "knock-down" of Eurasian watermilfoil shoots following two successive 2,4-D treatments in riverine plots on the Pend Oreille River, but plant biomass was only reduced by 50 percent the following growing season. These authors concluded that multiple 2,4-D treatments over several years would be required to effectively control Eurasian watermilfoil in selected Pend Oreille River locations.

Although contact herbicides, such as endothall, can provide excellent "knock-down" of standing shoot mass following relatively short exposure times, mature, robust target plants can resprout from unaffected rootcrowns a few weeks after treatment. Under optimal conditions, growth from these rootcrowns can reach nuisance levels during the same growing season of the initial herbicide application. Unlike contact herbicides, systemic

compounds, such as 2,4-D and triclopyr, can be translocated throughout the shoot and root systems, potentially providing complete kill of the target plant. However, systemics require a long exposure time, which normally limits their effectiveness in hydrodynamic environments leading to regrowth of treated plants in the same growing season.

Dye release rates from SRMDs used in this study demonstrated that this type of innovative application technique has the potential to improve efficacy of herbicides (particularly systemics) in flowing-water environments. If herbicide release rates can mimic the 7-day (168-hr) dye release rate from the SRMDs, CET relationships clearly demonstrate that the target plants will have received a lethal chemical dose. Preliminary results from laboratory experiments conducted at WES have shown that a small-scale version of the gypsum matrix released 2,4-D and triclopyr for periods of up to 7 days (Netherland 1992). Furthermore, an EPA-approved insecticide/gypsum matrix can release the active ingredients methoprene and temephos for up to 150 days (Netherland and Getsinger 1991). These findings indicate the need for continued evaluation of the SRMDs and/or other gypsum/herbicide formulations for controlling submersed plants.

# 4 Conclusions and Recommendations

## Conclusions

Water-exchange characteristics (derived from conventional dye applications and SRMD deployments) and results from previous laboratory concentration/exposure time studies indicate that the herbicides endothall, 2,4-D, and triclopyr are candidates for controlling Eurasian watermilfoil in selected locations on the Pend Oreille and Columbia River systems. Also, plot size can affect potential herbicide contact time around target vegetation, when using conventional application techniques. Finally, release rate characteristics of rhodamine WT from SRMDs demonstrate that these devices have the potential for controlled-release delivery of aquatic herbicides.

## Recommendations

Recommendations for the field evaluation of herbicides for controlling Eurasian watermilfoil in rivers of the Pacific Northwest are:

*a*. Evaluation sites for conventional applications should be at least 4-ha in size and located where potential herbicide contact time is greater than 8 hr, such as protected coves and bays, or riverine areas separated from the main channel flow.

*b*. The systemic herbicides 2,4-D and triclopyr should be evaluated in protected riverine and cove locations, while the contact herbicide endothall should be evaluated in open-river locations.

*c*. Effects of upstream and downstream dam operations should be evaluated with respect to herbicide treatments.

*d*. Gypsum matrix devices, and other potential carriers, should be evaluated for the slow release of 2,4-D and triclopyr in hydraulic channels or in the field.

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# Appendix A
# Slow Release Matrix Device Patent Information

# United States Patent [19]

**Sjogren**

[11] **Patent Number: 4,732,762**

[45] **Date of Patent: Mar. 22, 1988**


[54] **TIMED RELEASE PEST CONTROL COMPOSITION AND MEANS**


[75] Inventor: Robert D. Sjogren, St. Paul, Minn.

[73] Assignee: Metropolitan Mosquito Control District, St. Paul, Minn.



[21] Appl. No.: 714,341

[22] Filed: Mar. 20, 1985

**Related U.S. Application Data**

[63] Continuation of Ser. No. 472,922, Mar. 7, 1983, abandoned.

[51] Int. Cl.[4] ..... A01N 25/34

[52] U.S. Cl. ..... 424/409; 71/67; 71/DIG. 5; 424/408; 514/722

[58] Field of Search ..... 71/67, DIG. 5; 424/16, 424/19, 22, 23, 409, 408; 514/722



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*Primary Examiner*—Catherine L. Mills

*Attorney, Agent, or Firm*—Merchant, Gould, Smith, Edell, Welter & Schmidt



[57] **ABSTRACT**

A controlled slow release pest control composition comprising an encapsulated pesticide, carbon and plaster.


23 Claims, No Drawings

# United States Patent [19]

**Sjogren**

[11] **Patent Number: 4,670,039**

[45] **Date of Patent: Jun. 2, 1987**

[54] **TIMED RELEASE FERTILIZER COMPOSITION AND MEANS**


[75] **Inventor:** Robert D. Sjogren, St. Paul, Minn.

[73] **Assignee:** Metropolitan Mosquito Control District, St. Paul, Minn.



[21] **Appl. No.:** 838,423

[22] **Filed:** Mar. 7, 1986

**Related U.S. Application Data**

[63] Continuation of Ser. No. 717,325, Mar. 14, 1985, abandoned, which is a continuation of Ser. No. 472,737, Mar. 7, 1983, abandoned.

[51] **Int. Cl.**[4] ..... C05B 11/04; C05B 7/00; A01N 25/00; C04B 11/00

[52] **U.S. Cl.** ..... 71/34; 71/51; 71/64.11; 71/64.13; 71/903; 106/110

[58] **Field of Search** ..... 71/34, 47, 51, 64.01, 71/64.11, 64.13, 903; 106/110


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*Primary Examiner*—Donald R. Valentine

*Attorney, Agent, or Firm*—Merchant, Gould, Smith, Edell, Welter & Schmidt

[57] **ABSTRACT**


A controlled slow release fertilizer composition comprising an encapsulated fertilizer, carbon and plaster.


23 Claims, No Drawings

# Appendix B
# River Discharge Rates and Dye Concentrations, Pend Oreille River, Washington

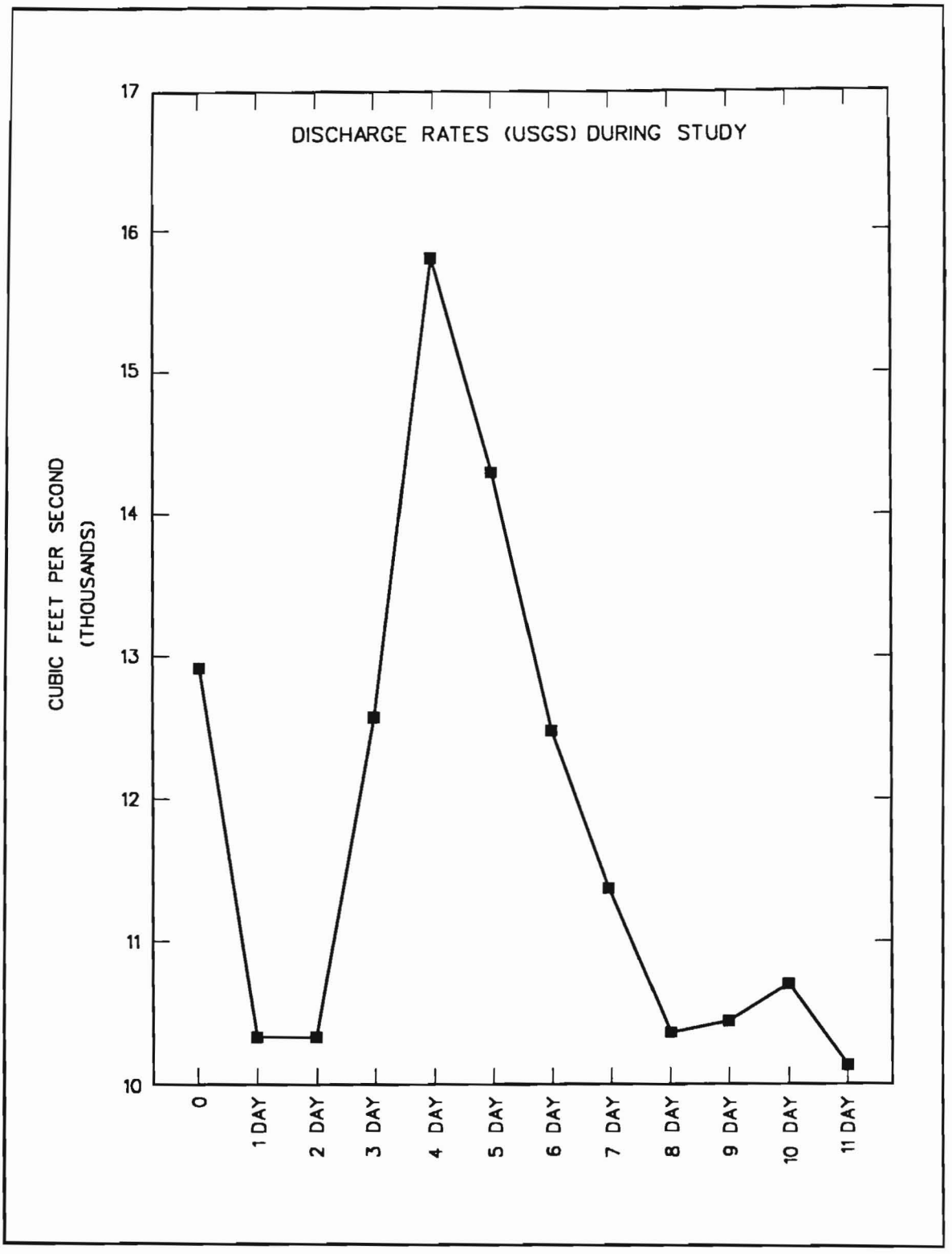


Figure B1. Discharge rates from Albeni Falls Dam during SRMD studies on the Pend Oreille River, Washington, 1990

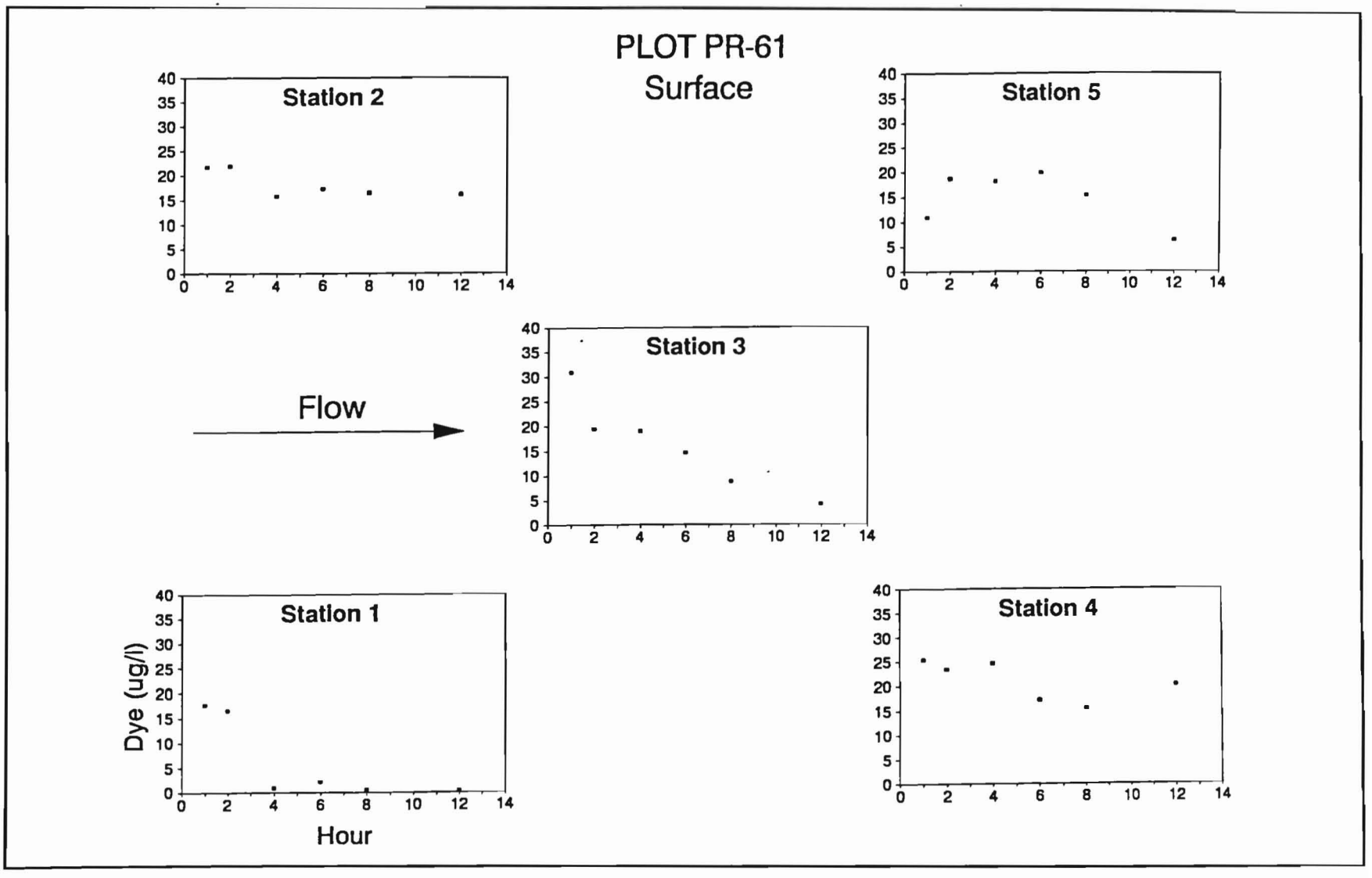


Figure B2. Dye concentrations (µg/L) in Plot PR-61 at surface in Pend Oreille River, Washington, 1990

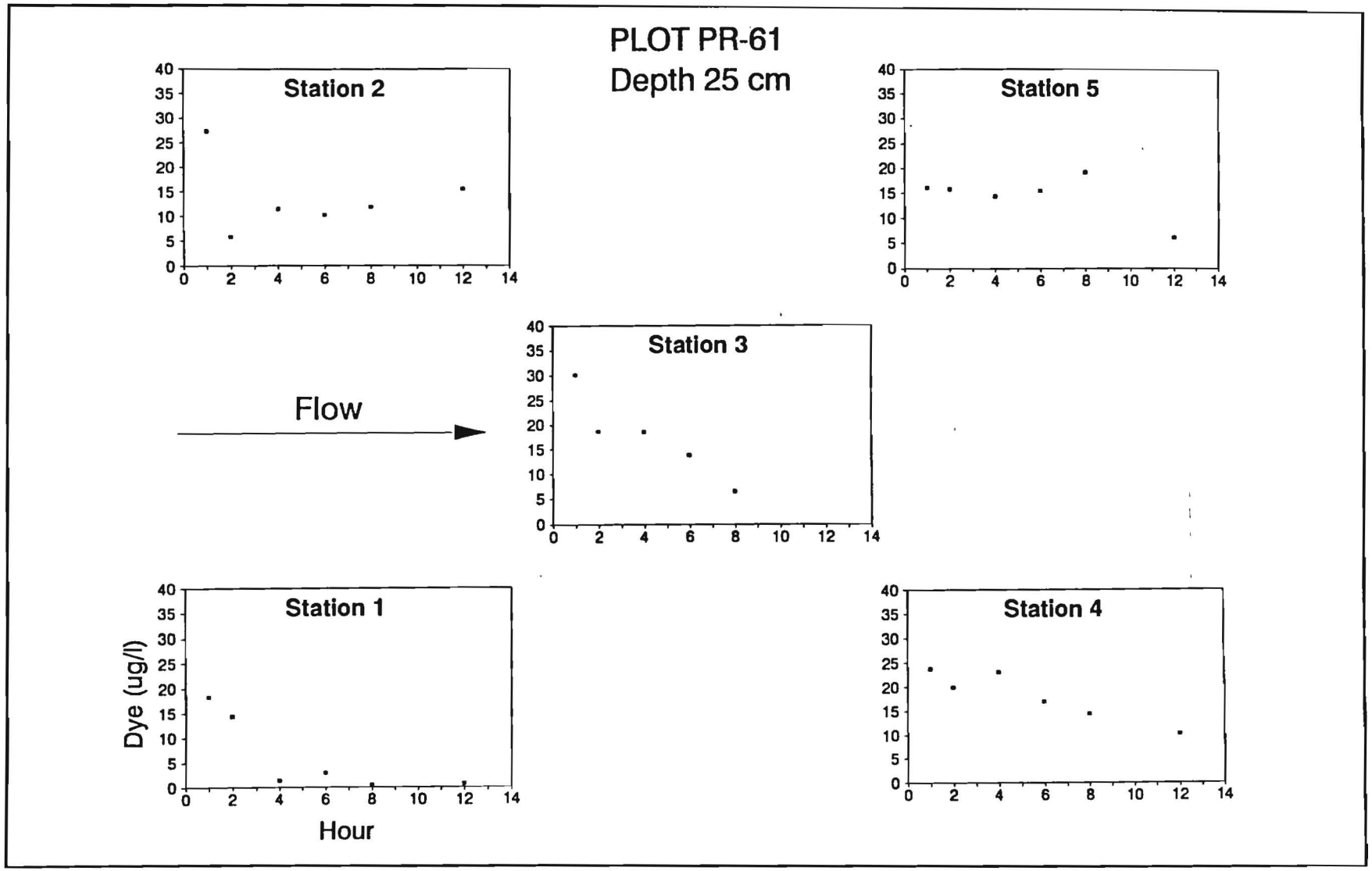


Figure B3. Dye concentrations (µg/L) in Plot PR-61 at 25-cm depth in Pend Oreille River, Washington, 1990

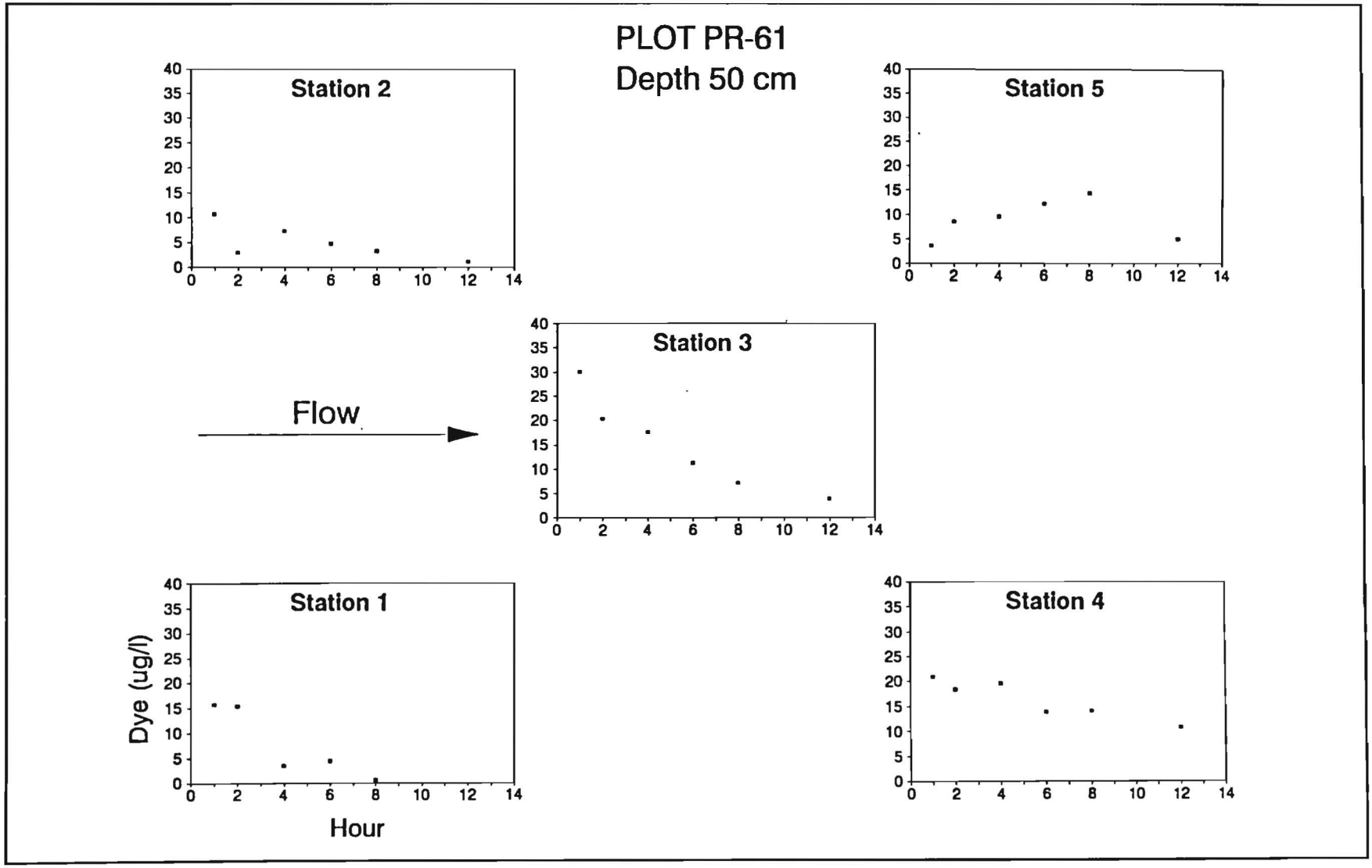


Figure B4. Dye concentrations (µg/L) in Plot PR-61 at 50-cm depth in Pend Oreille River, Washington, 1990

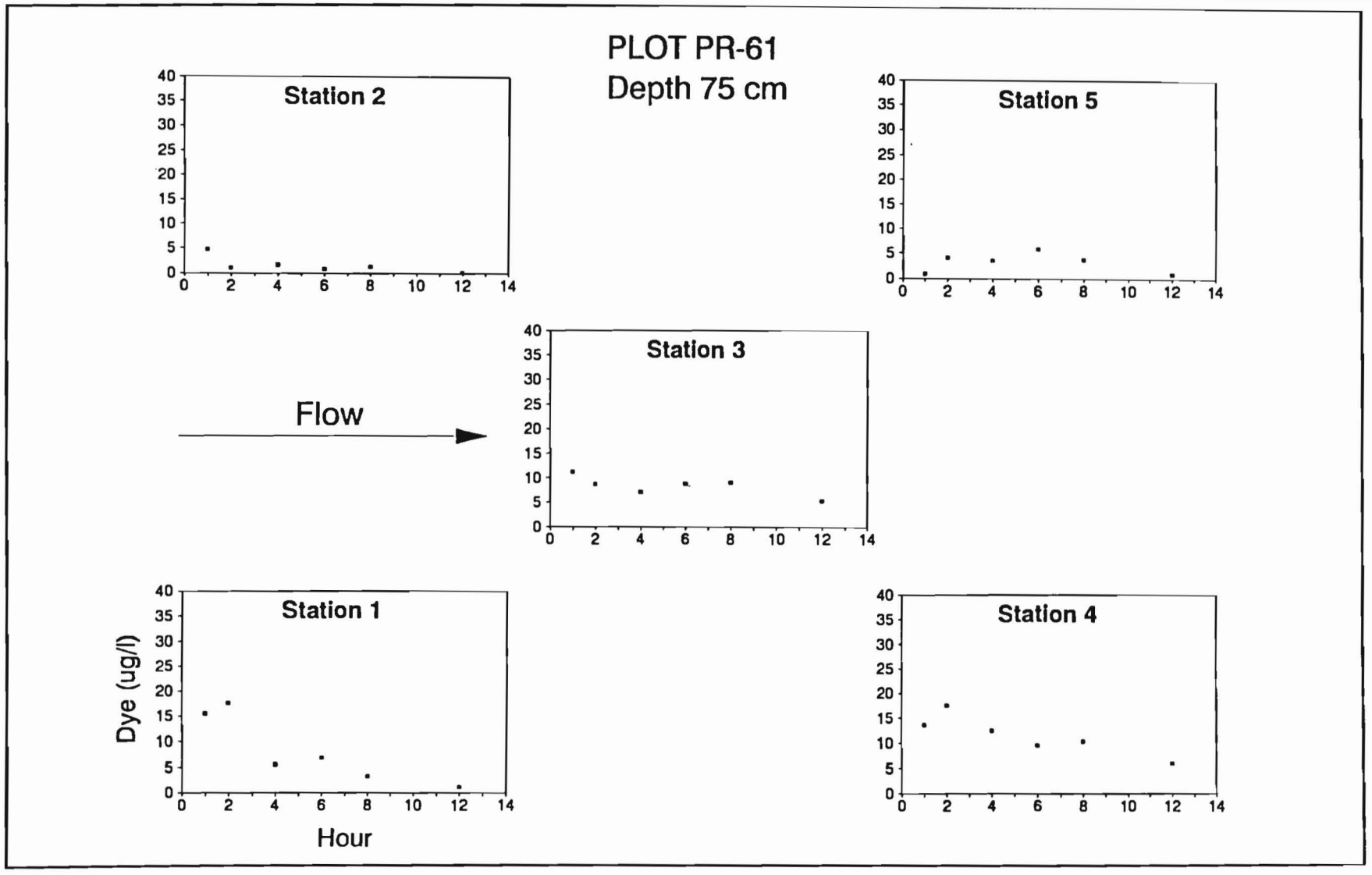


Figure B5. Dye concentrations (µg/L) in Plot PR-61 at 75-cm depth in Pend Oreille River, Washington, 1990

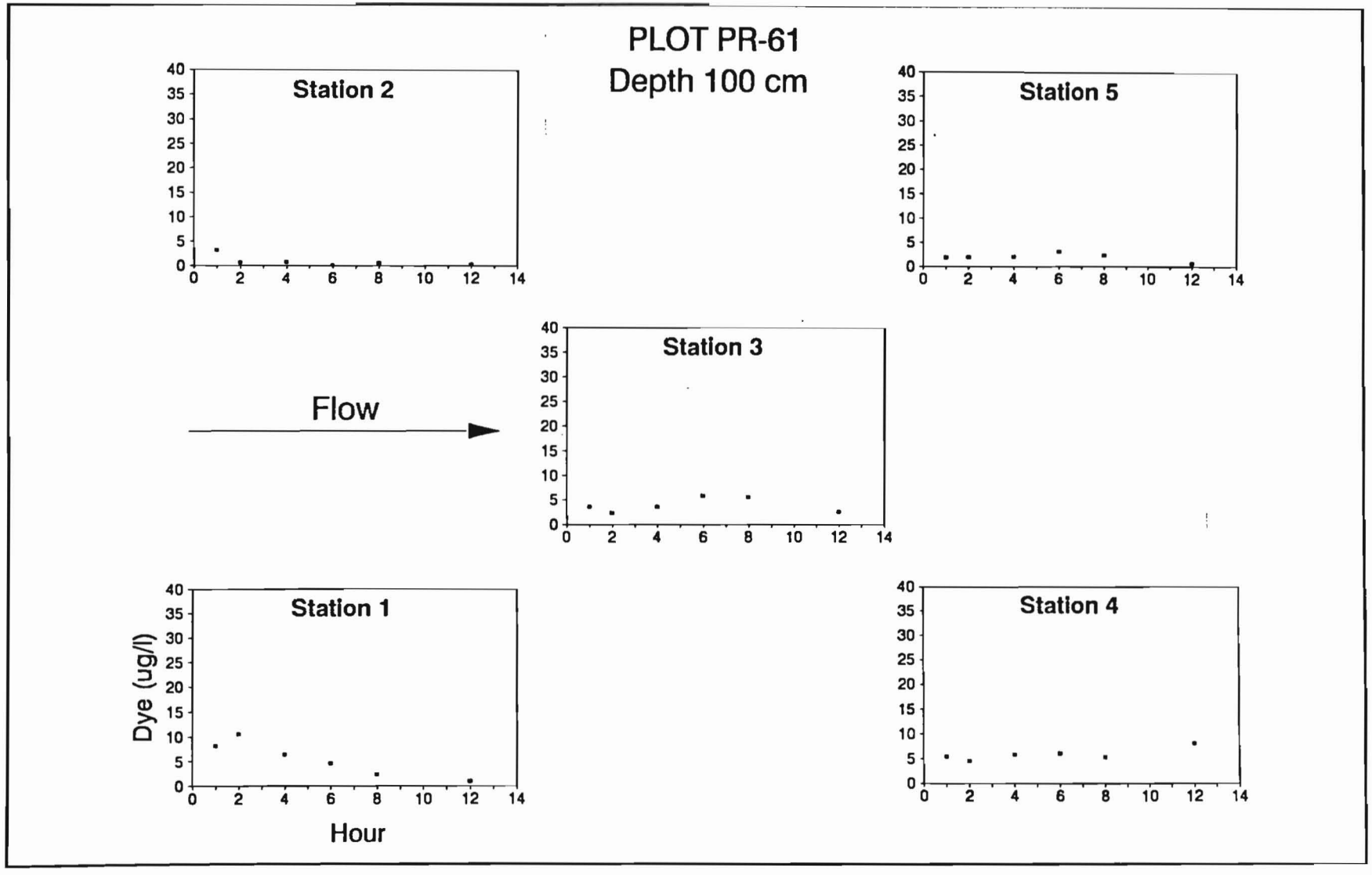


Figure B6. Dye concentrations (µg/L) in Plot PR-61 at 100-cm depth in Pend Oreille River, Washington, 1990

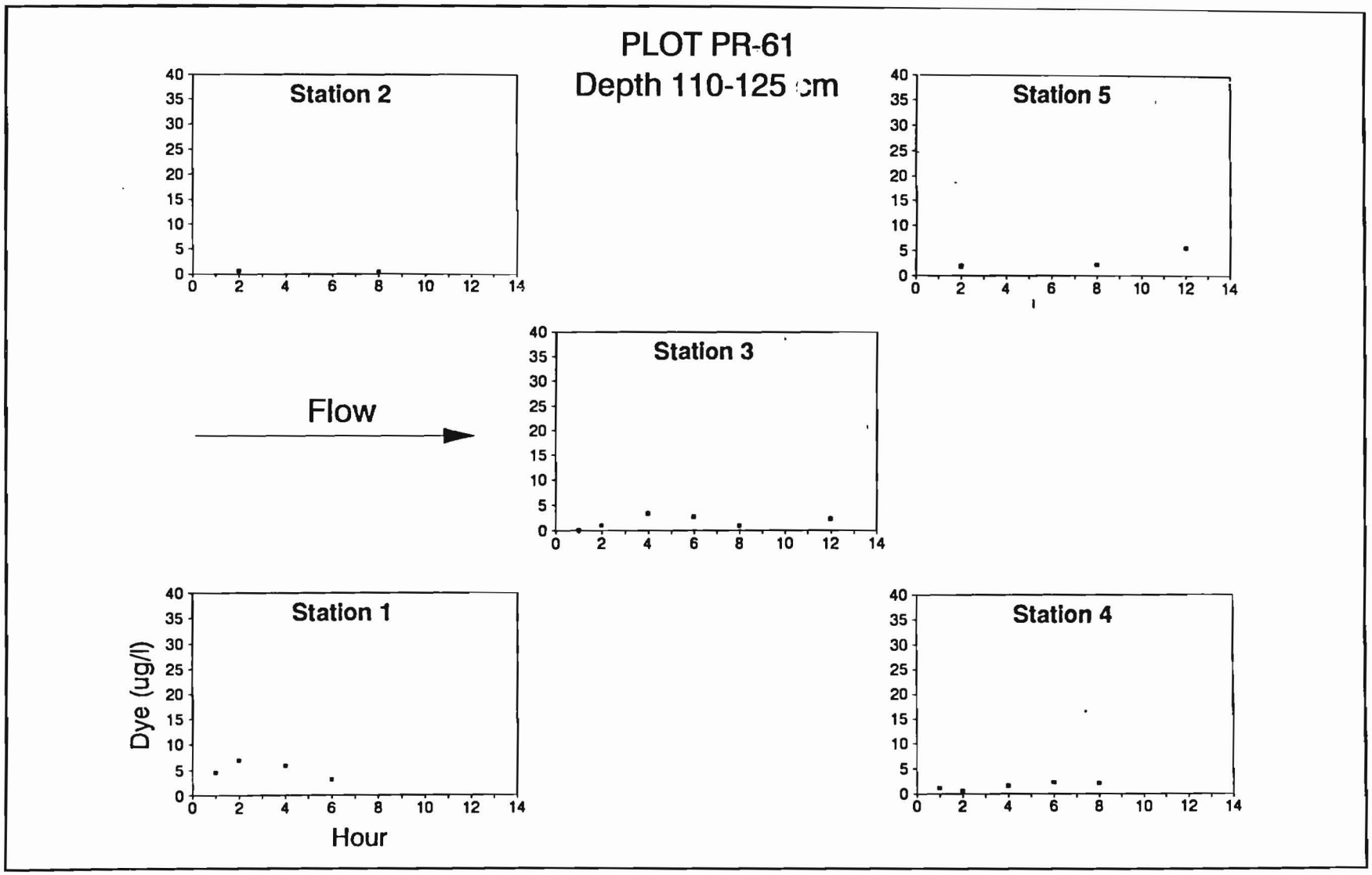


Figure B7. Dye concentrations (µg/L) in Plot PR-61 at 110- to 125-cm depth in Pend Oreille River, Washington, 1990

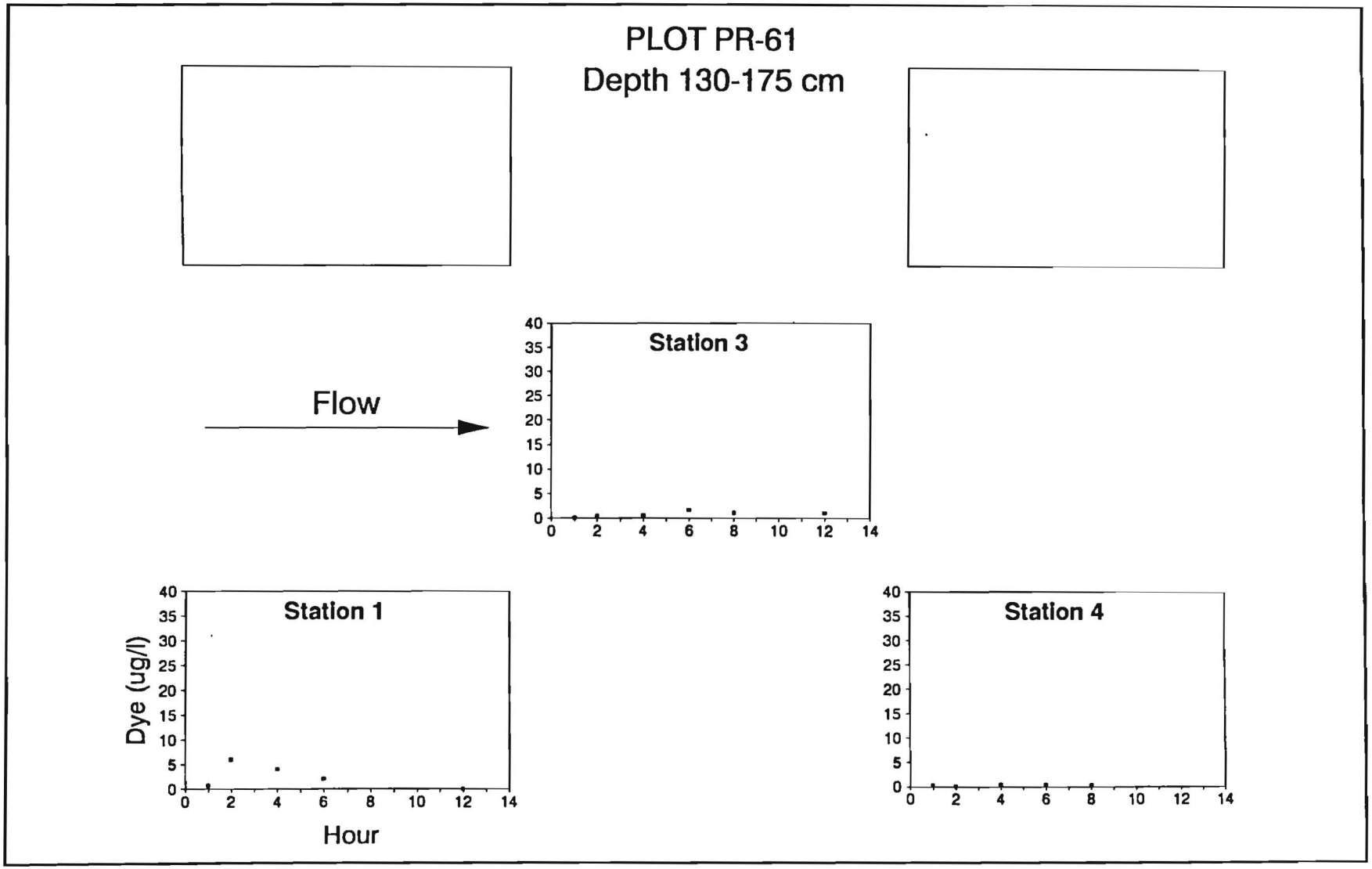


Figure B8. Dye concentrations (µg/L) in Plot PR-61 at 130- to 175-cm depth in Pend Oreille River, Washington, 1990

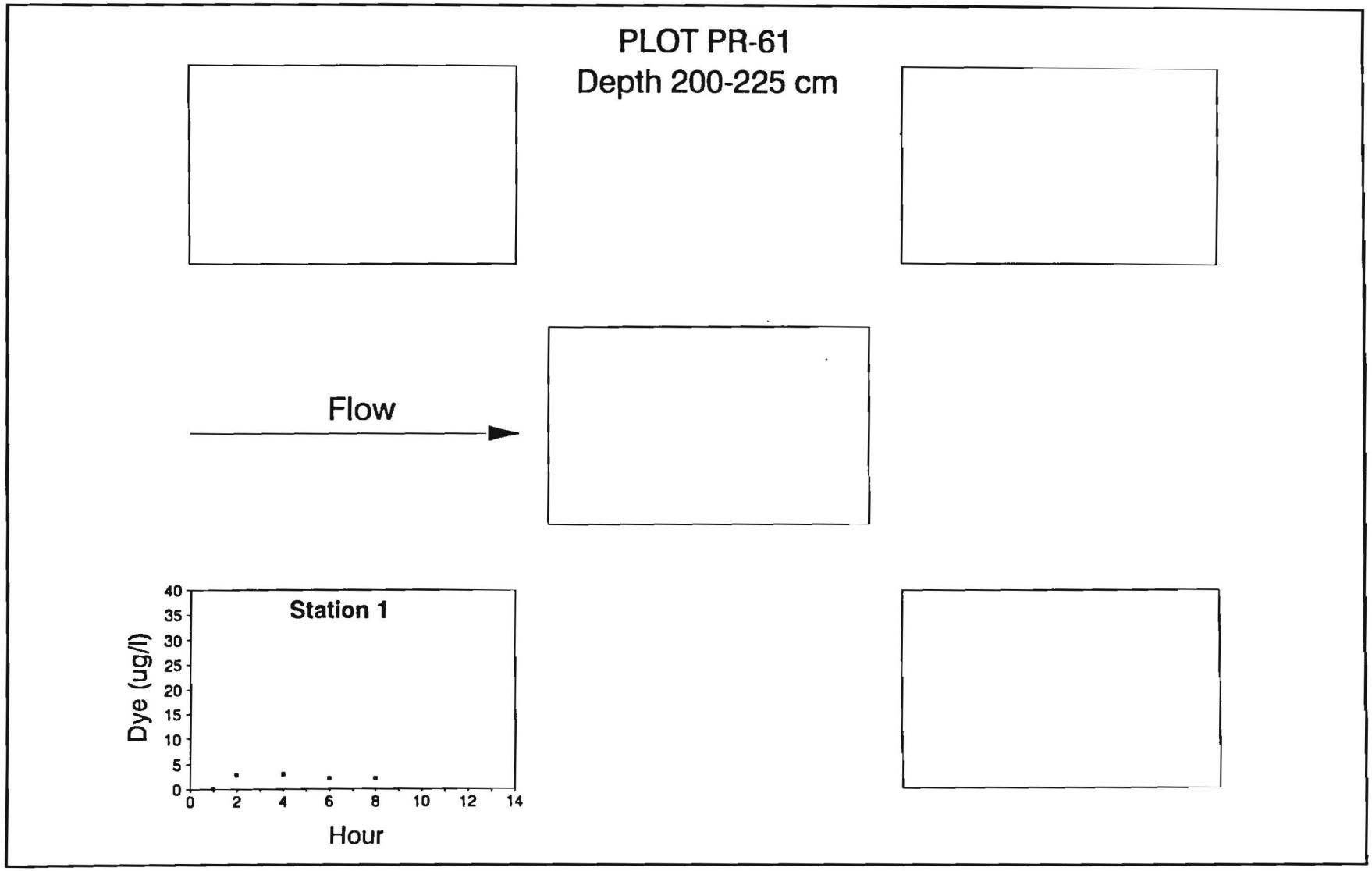


Figure B9. Dye concentrations (µg/L) in Plot PR-61 at 220- to 225-cm depth in Pend Oreille River, Washington, 1990

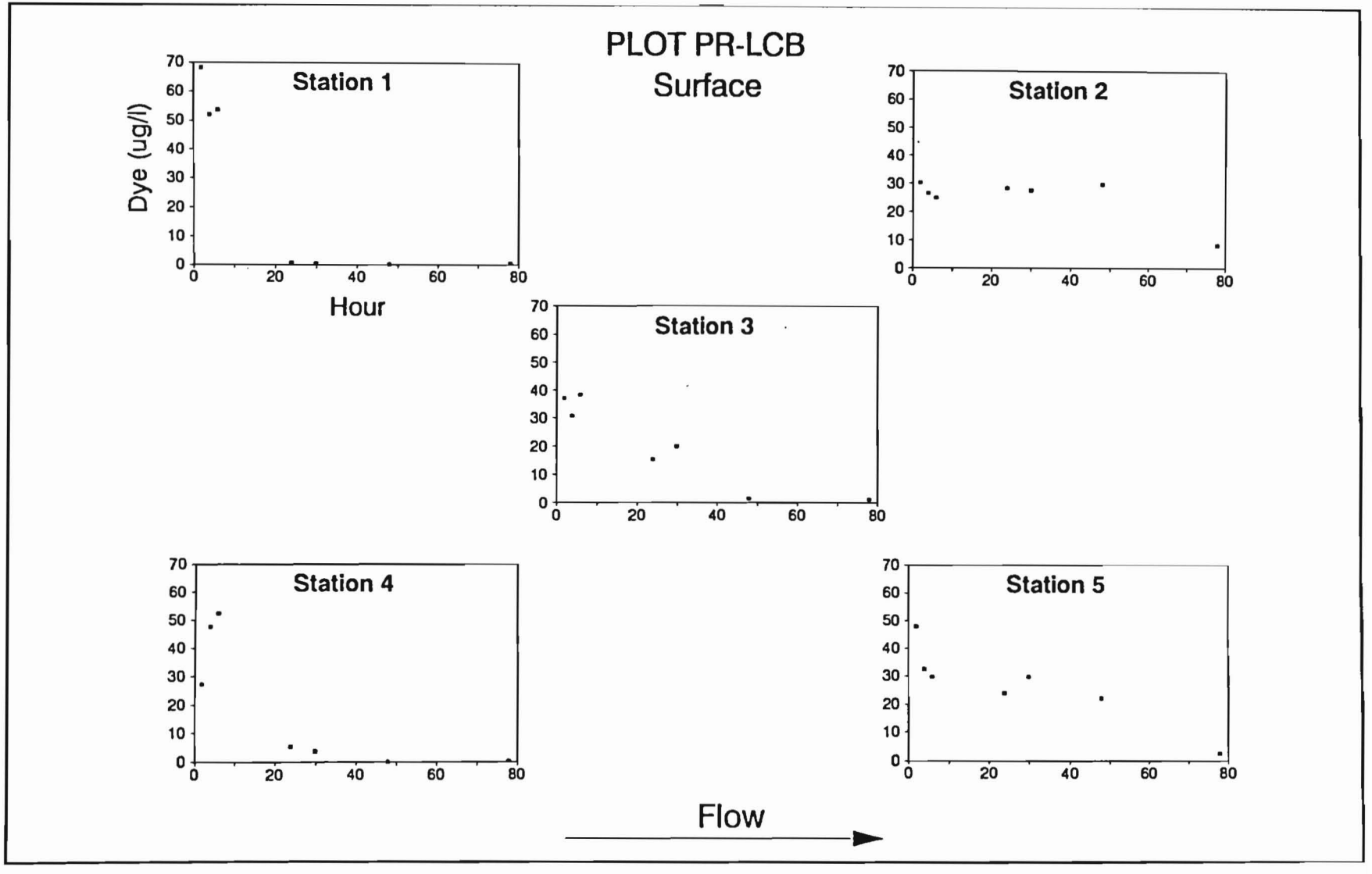


Figure B10. Dye concentrations (µg/L) in Plot PR-LCB at surface in Pend Oreille River, Washington, 1990

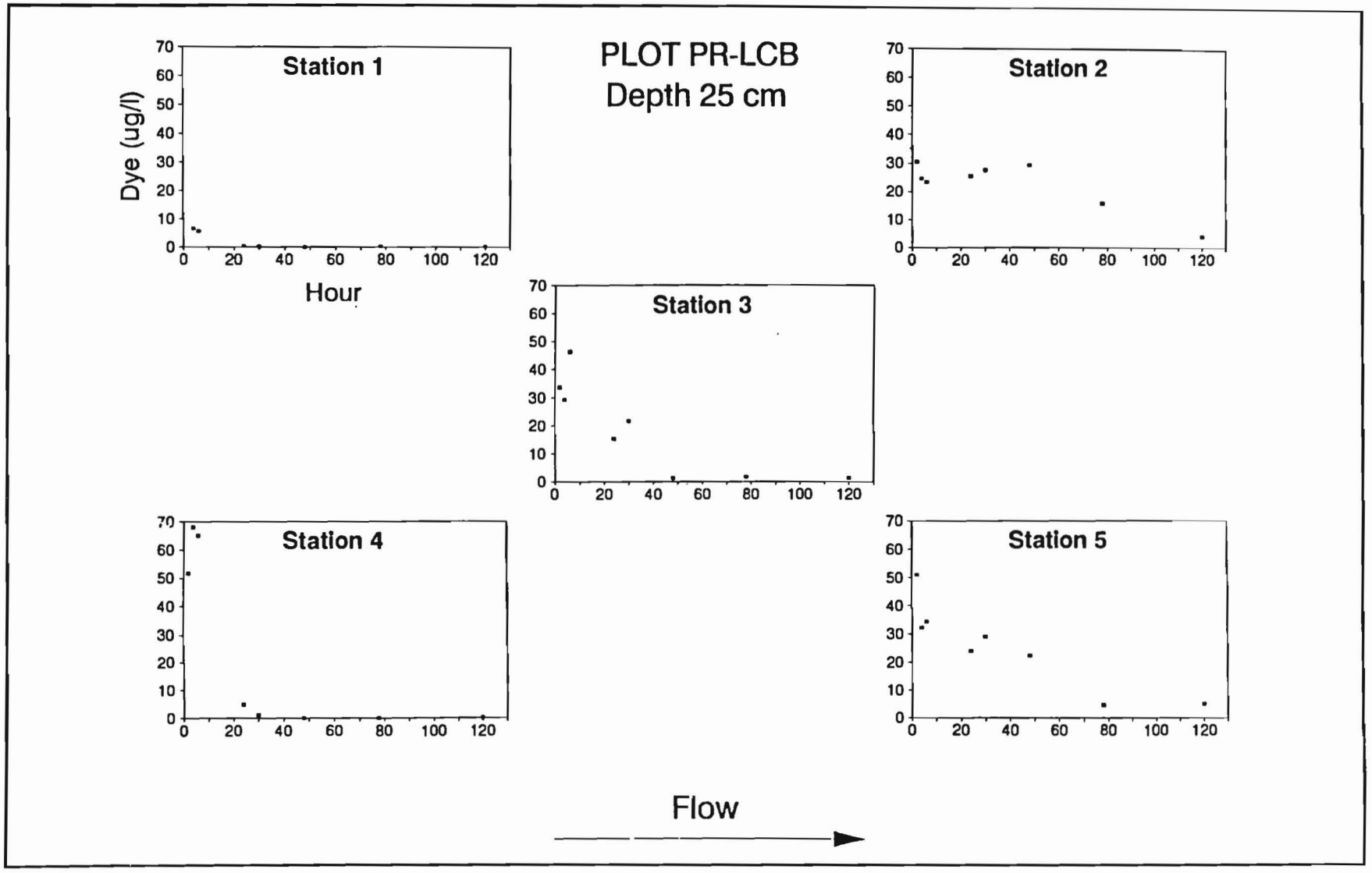


Figure B11. Dye concentrations (µg/L) in Plot PR-LCB at 2-cm depth in Pend Oreille River, Washington, 1990

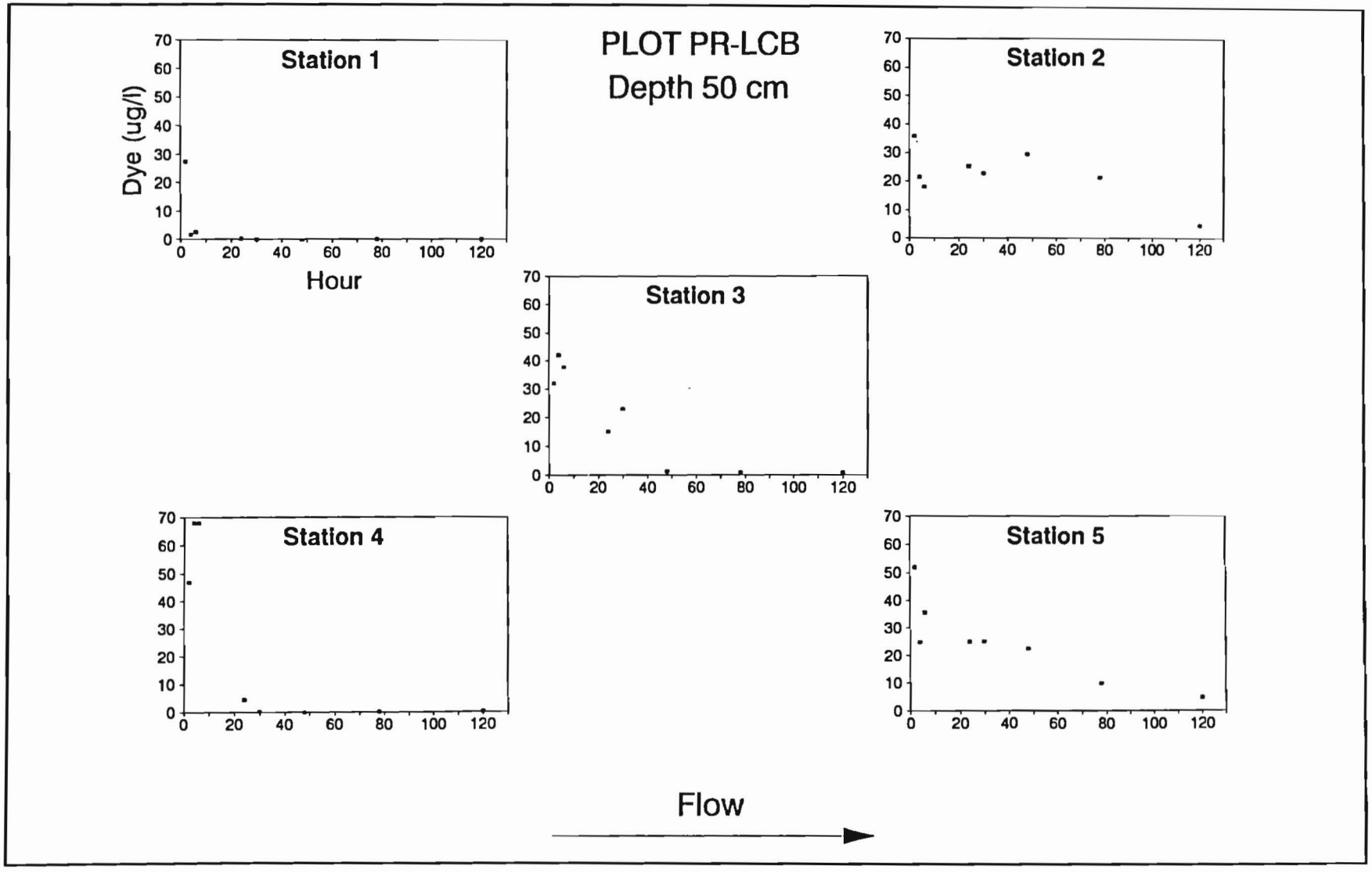


Figure B12. Dye concentrations (µg/L) in Plot PR-LCB at 50-cm depth in Pend Oreille River, Washington, 1990

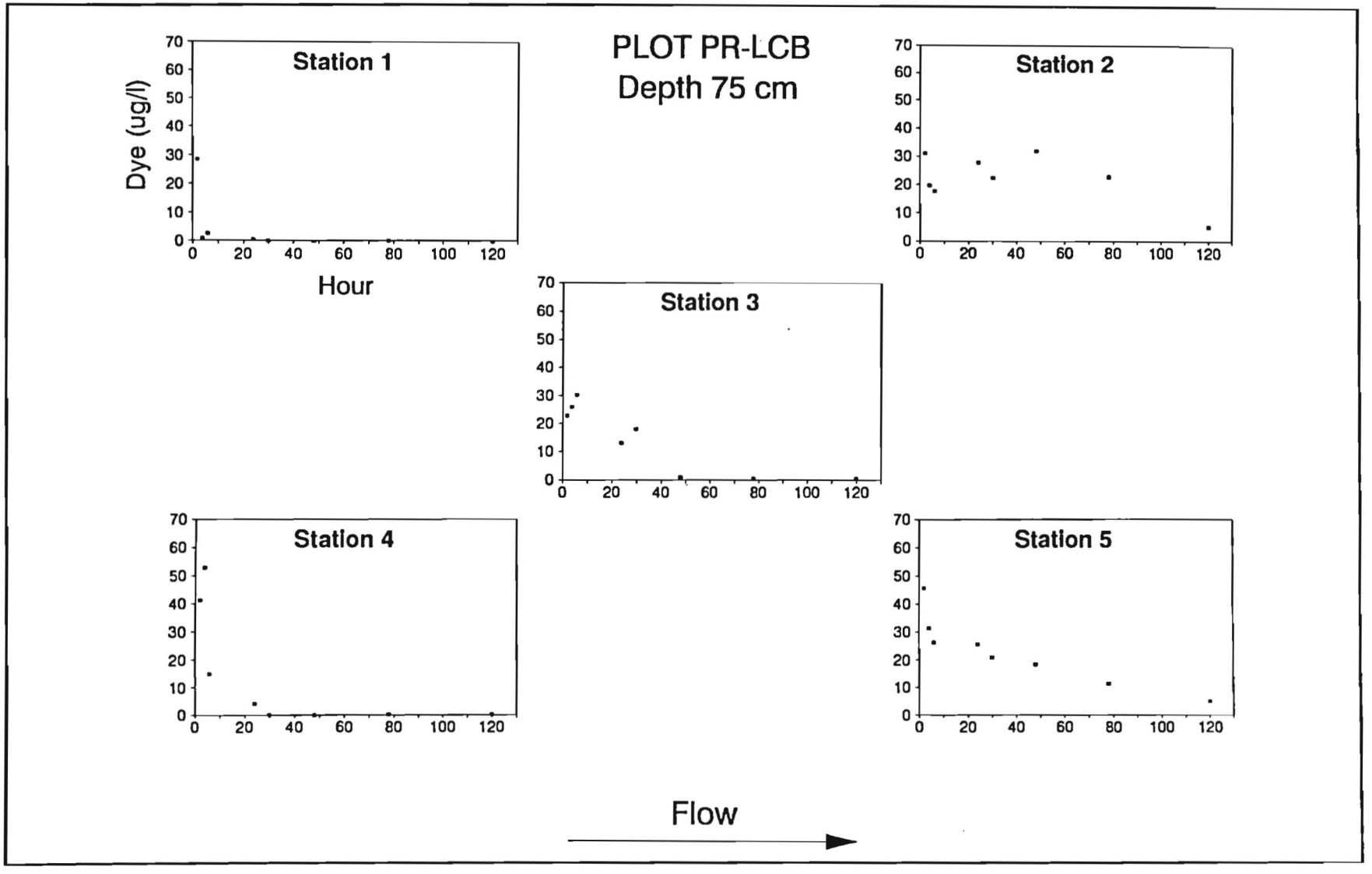


Figure B13. Dye concentrations (µg/L) in Plot PR-LCB at 75-cm depth in Pend Oreille River, Washington, 1990

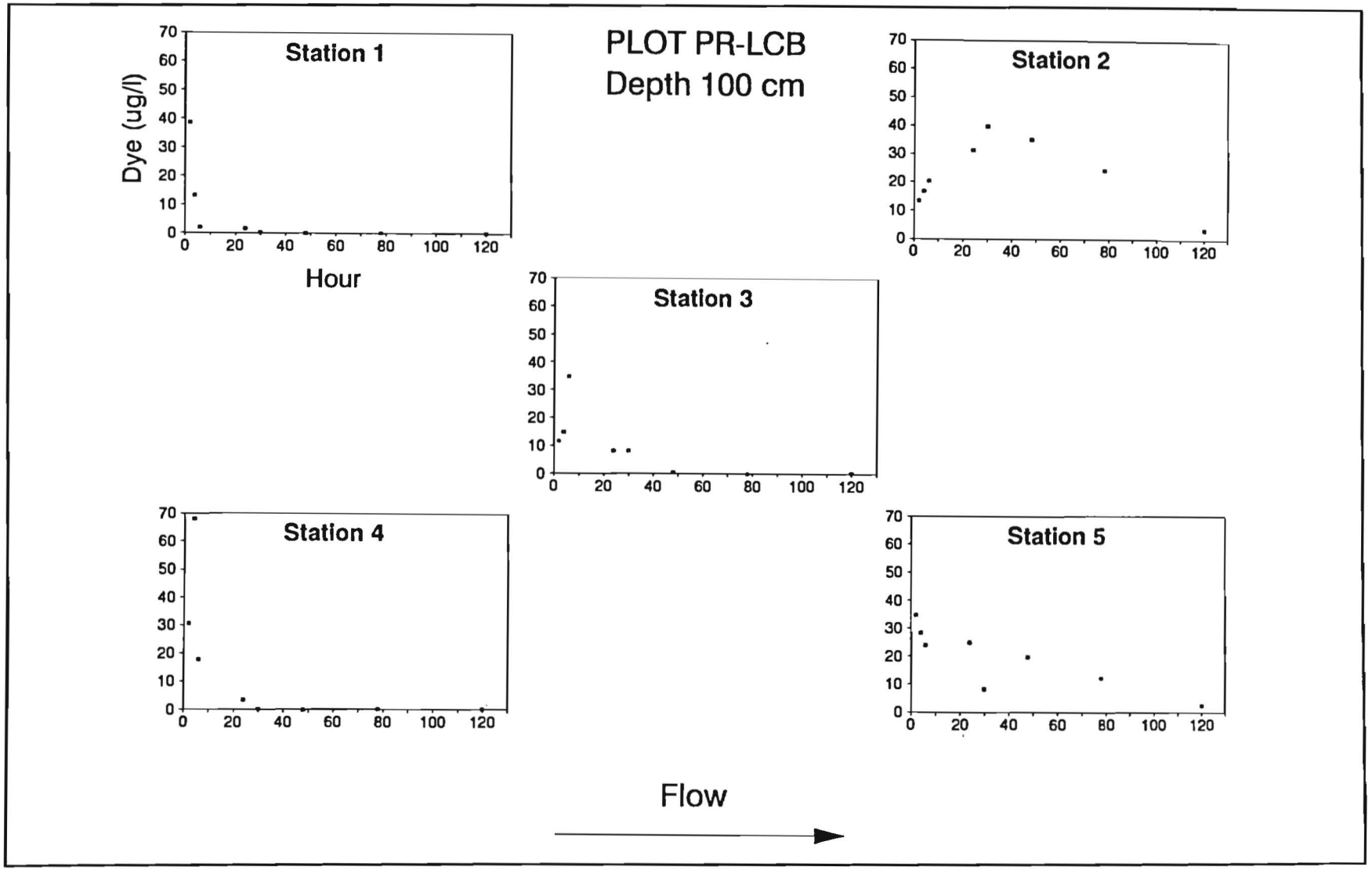


Figure B14. Dye concentrations (µg/L) in Plot PR-LCB at 100-cm depth in Pend Oreille River, Washington, 1990

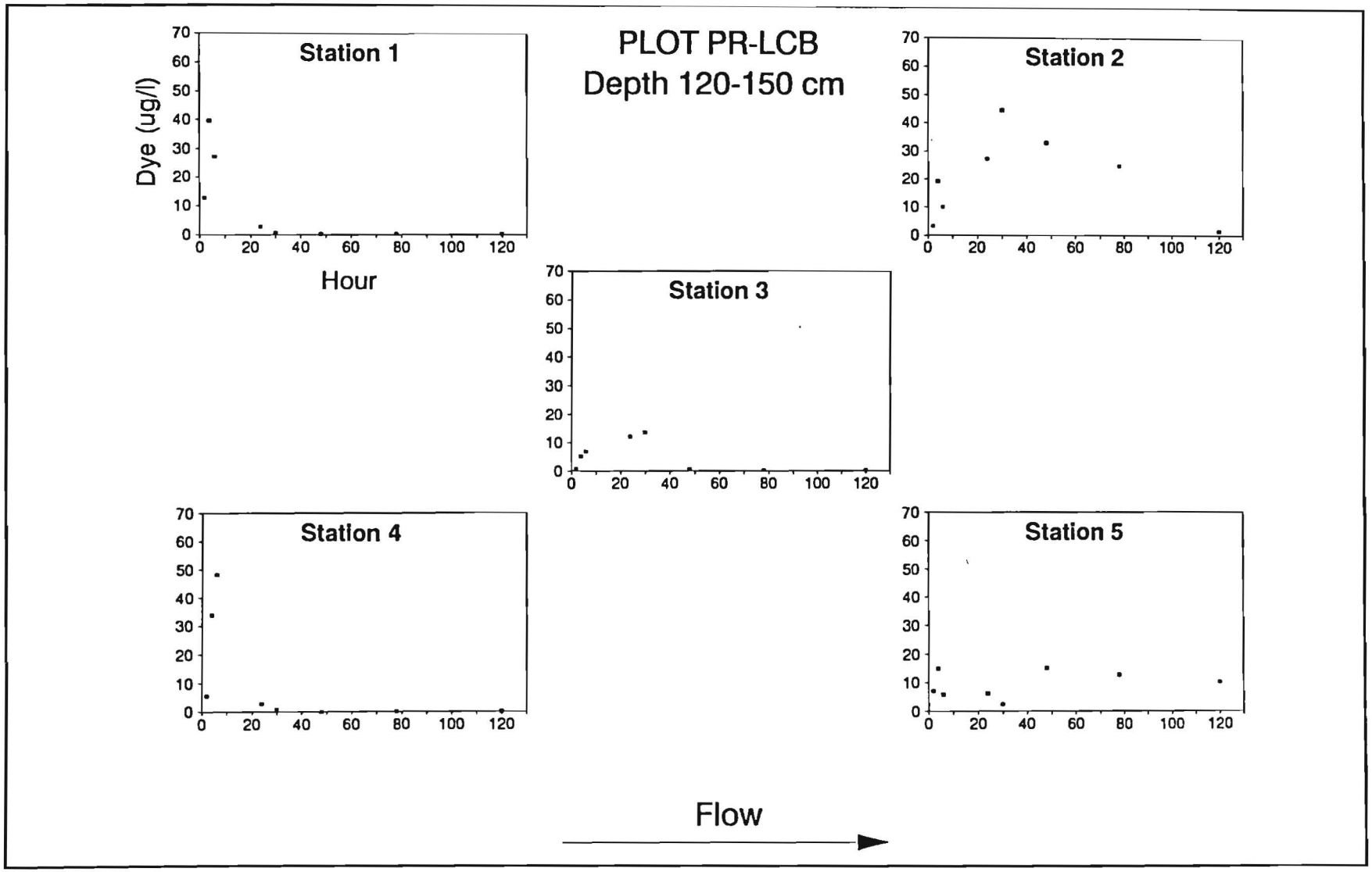


Figure B15. Dye concentrations (µg/L) in Plot PR-LCB at 120- to 150-cm depth in Pend Oreille River, Washington, 1990

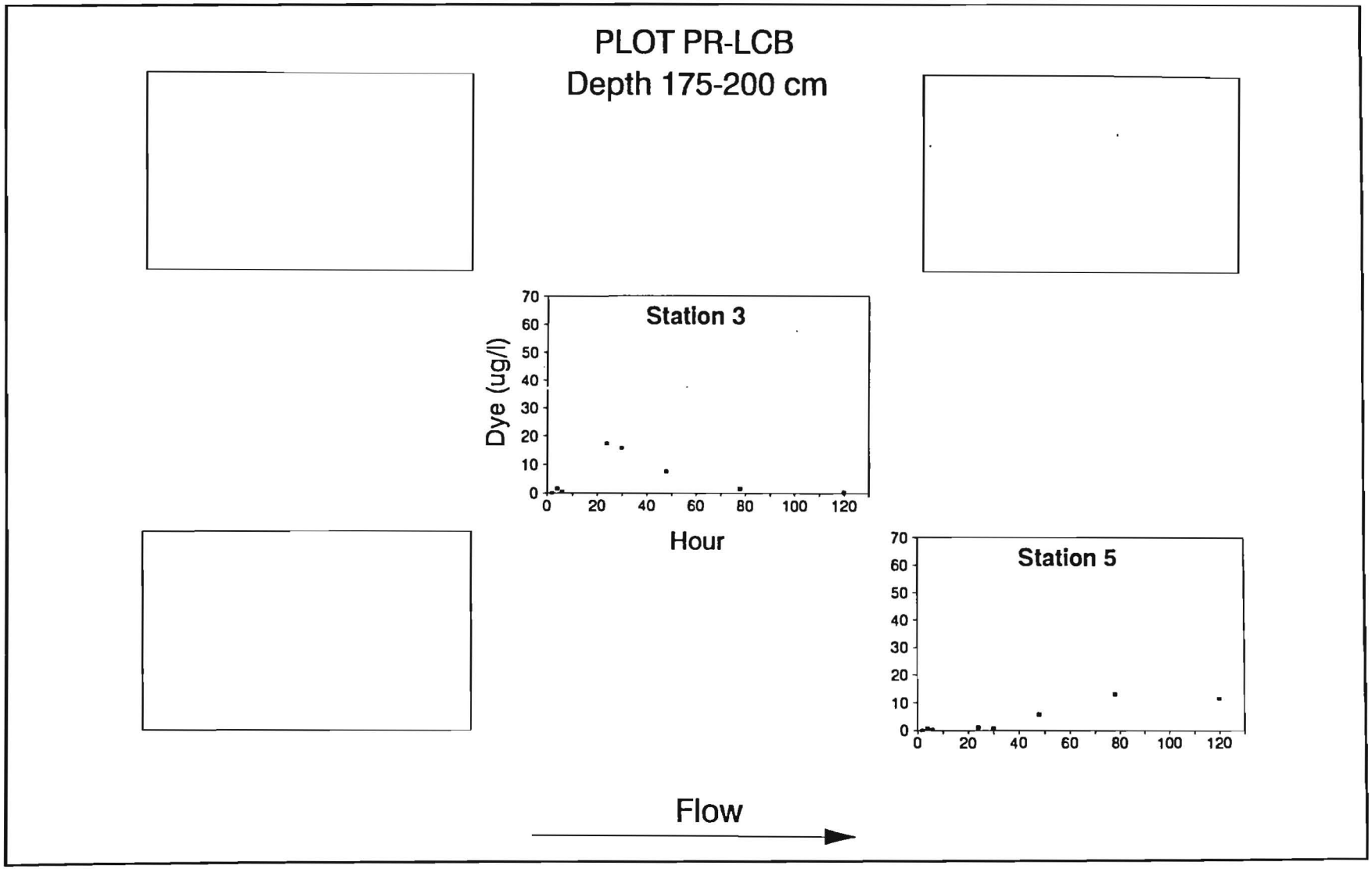


Figure B16. Dye concentrations (µg/L) in Plot PR-LCB at 175- to 200-cm depth in Pend Oreille River, Washington, 1990

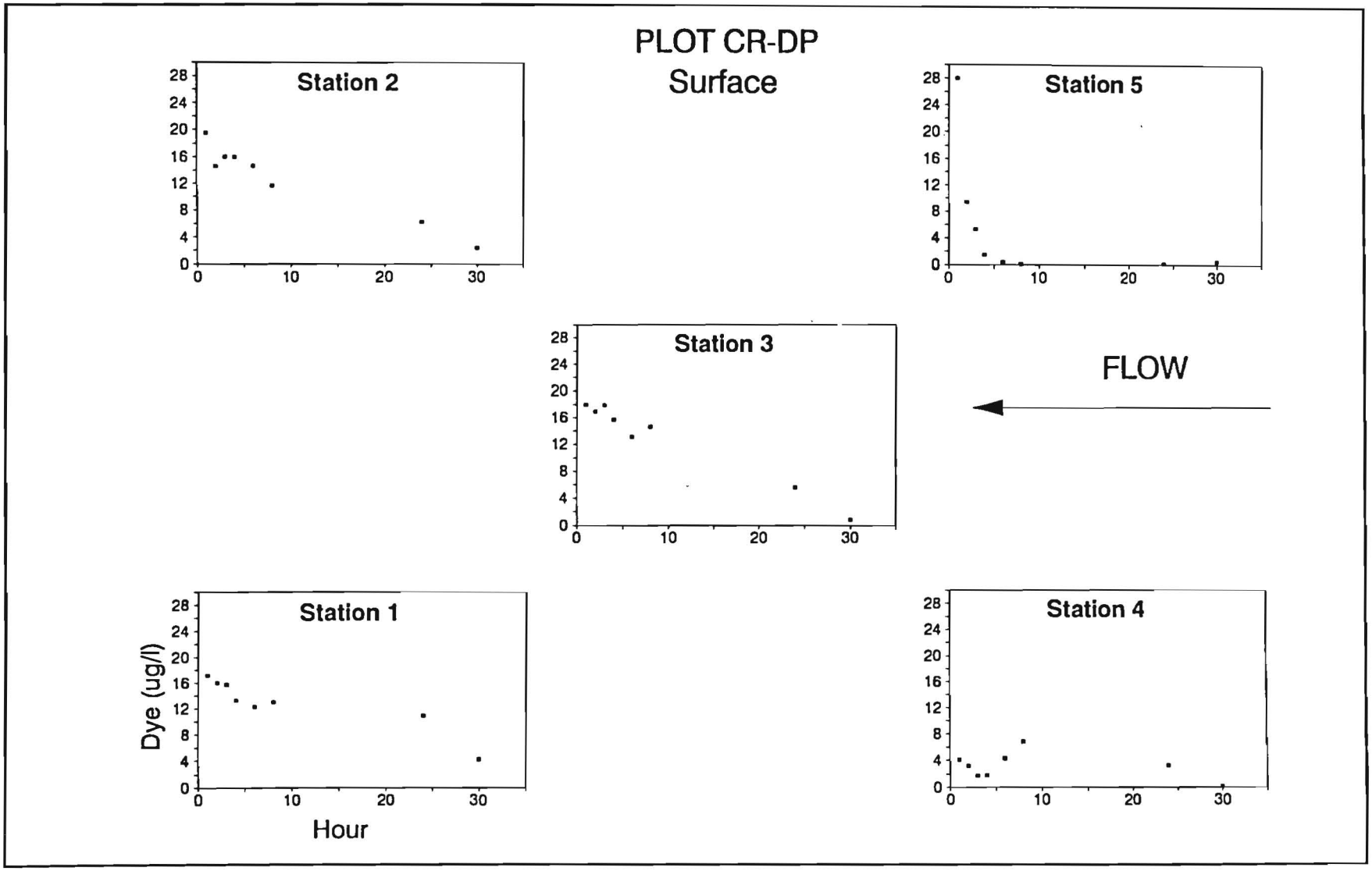


Figure B17. Dye concentrations (µg/L) in Plot CR-DP at surface in Columbia River, Washington, 1990

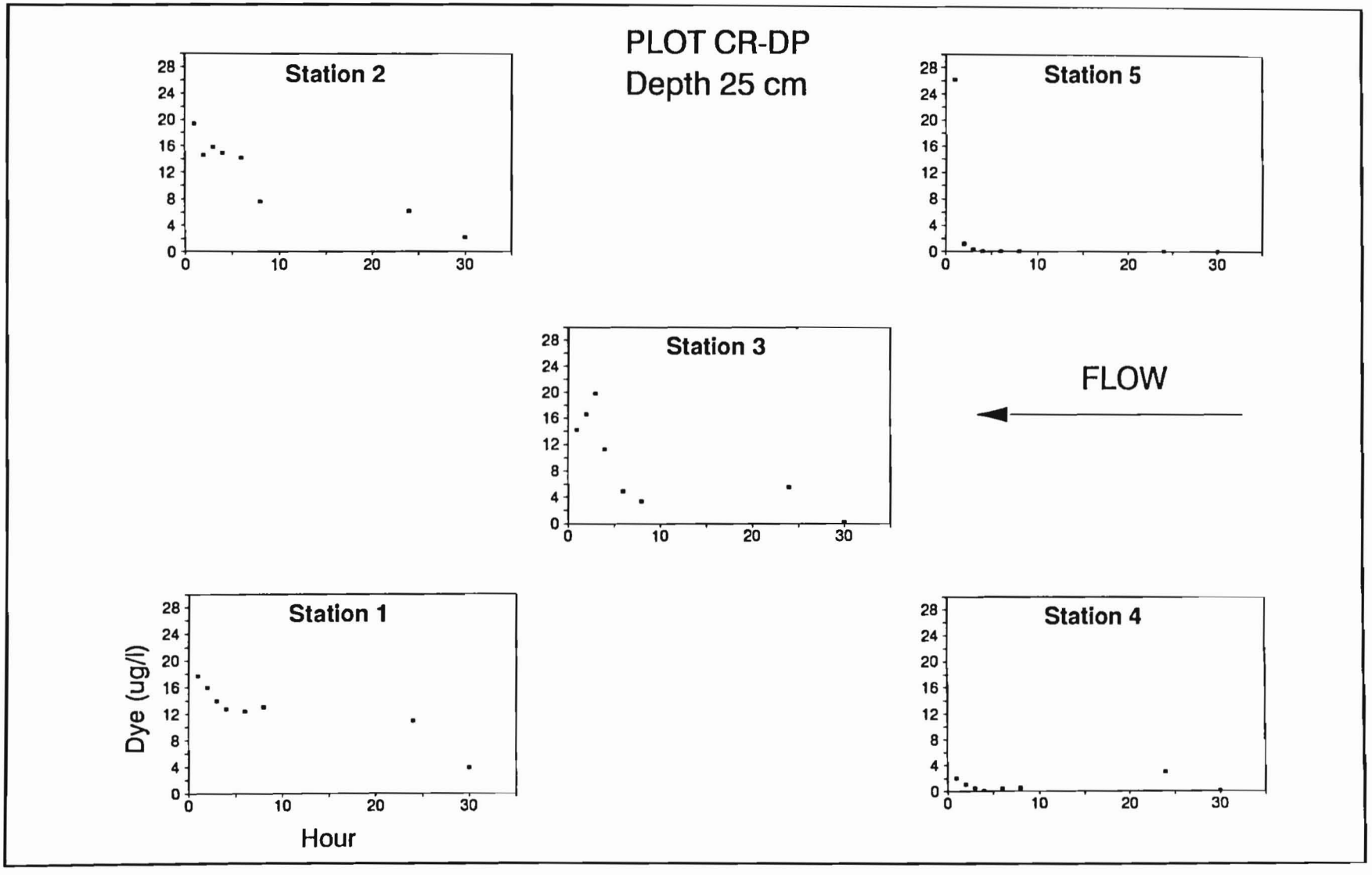


Figure B18. Dye concentrations (µg/L) in Plot CR-DP at 25-cm depth in Columbia River, Washington, 1990

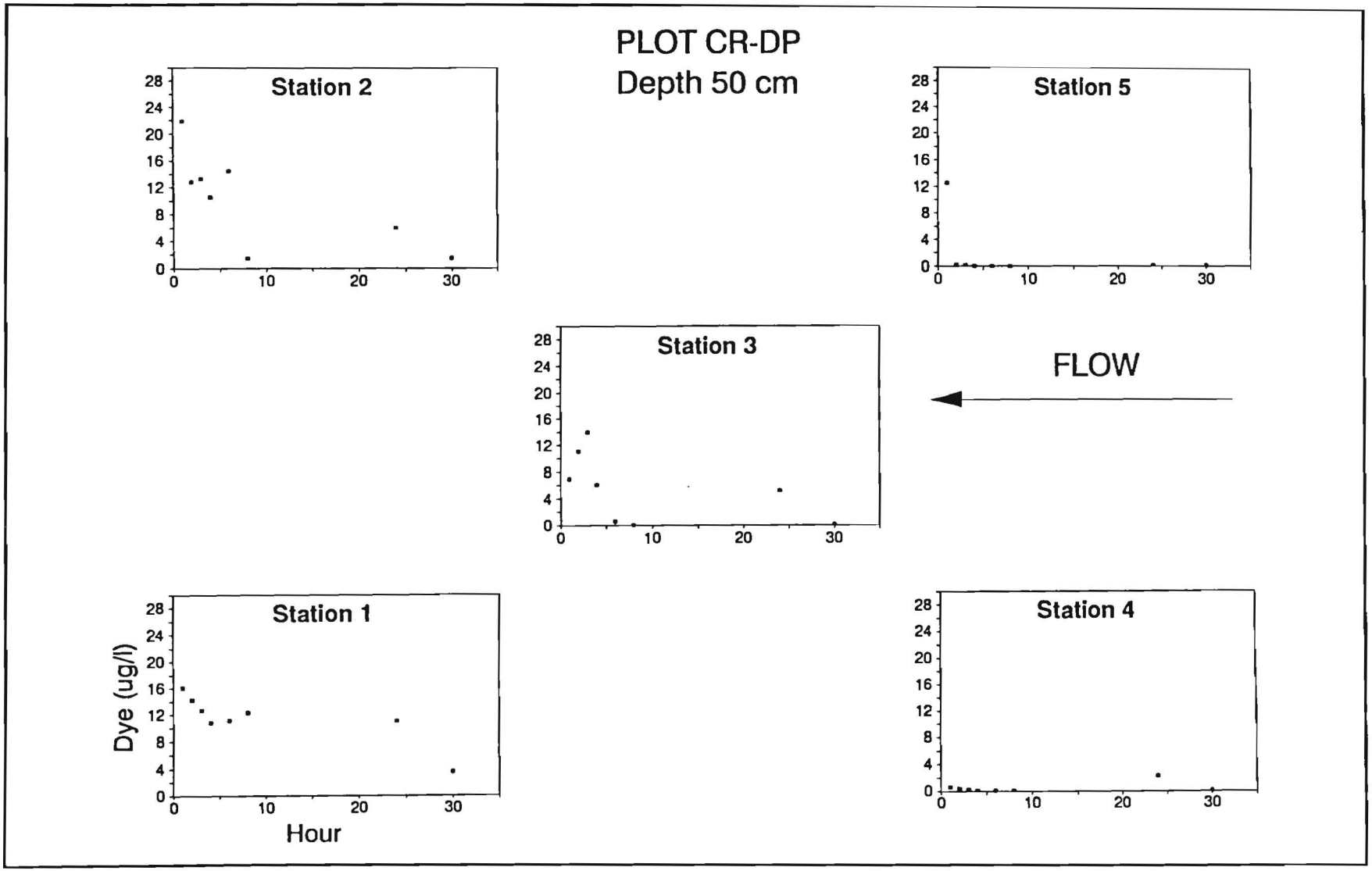


Figure B19. Dye concentrations (µg/L) in Plot CR-DP at 50-cm depth in Columbia River, Washington, 1990

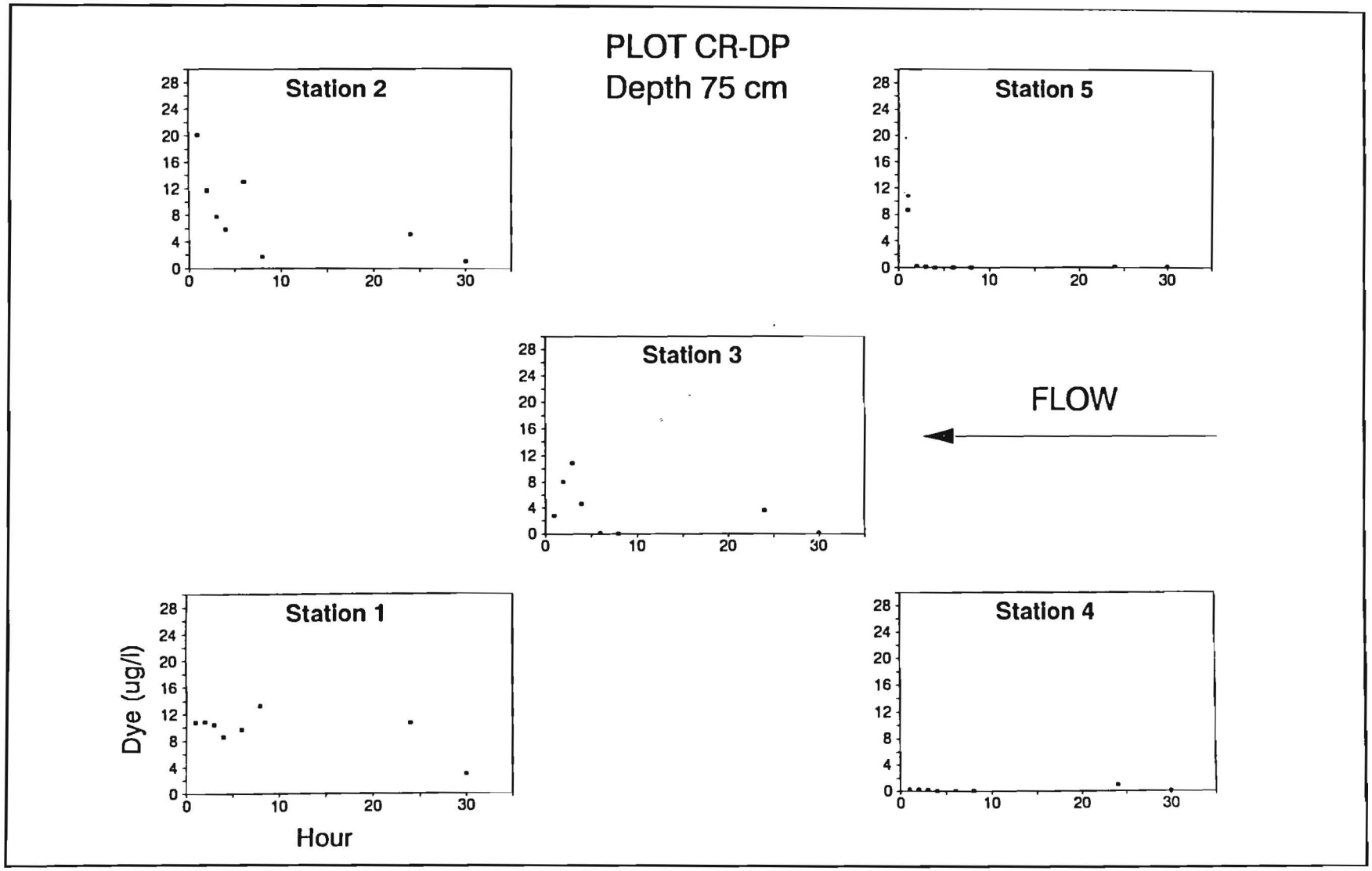


Figure B20. Dye concentrations (µg/L) in Plot CR-DP at 75-cm in Columbia River, Washington, 1990

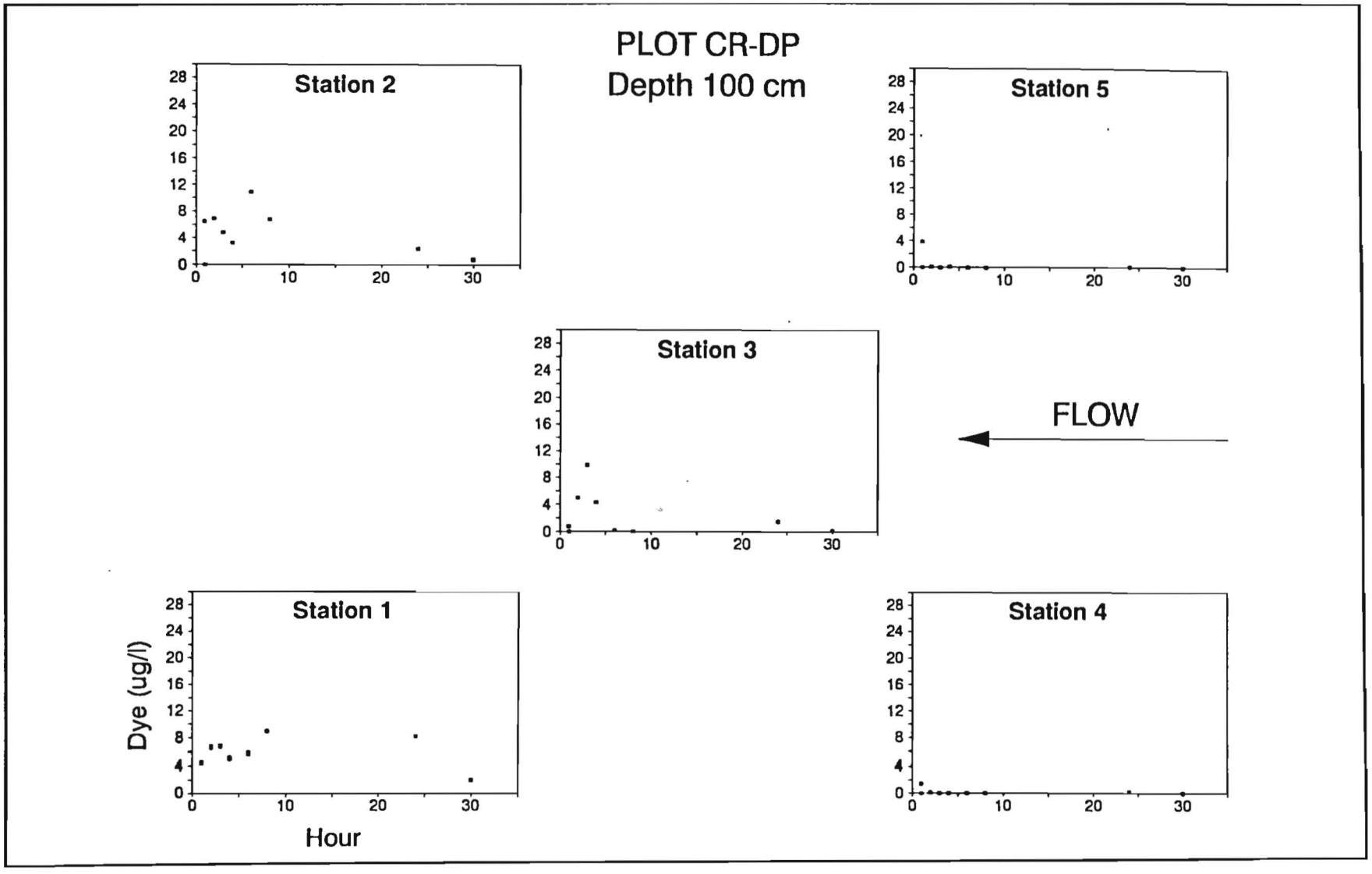


Figure B21. Dye concentrations (µg/L) in Plot CR-DP at 100-cm depth in Columbia River, Washington, 1990

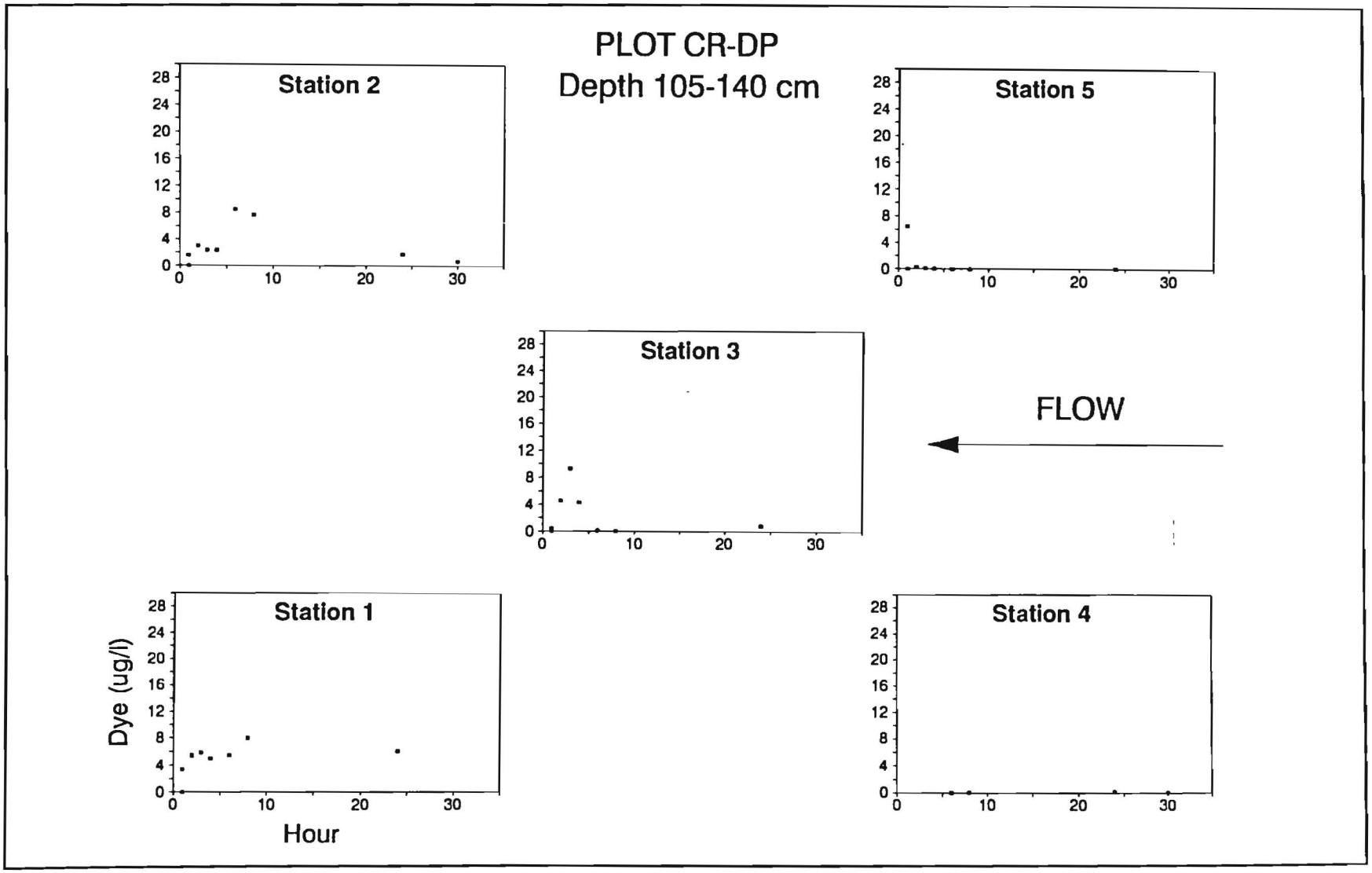


Figure B22. Dye concentrations (µg/L) in Plot CR-DP at 105- to 140-cm depth in Columbia River, Washington, 1990

# REPORT DOCUMENTATION PAGE

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**13. ABSTRACT** *(Maximum 200 words)*

The submersed plant Eurasian watermilfoil (*Myriophyllum spicatum* L.), continues to adversely impact areas in the high water exchange environment of the Columbia River system. Studies designed to characterize water movement and to evaluate a slow release matrix device (SRMD) for improving the chemical control of that target plant were conducted in the Pend Oreille and Columbia Rivers, Washington, in August 1990. A series of rhodamine WT dye treatments were applied (using conventional, liquid application techniques) to 4-ha plots representing milfoil-dominated riverine and cove sites to estimate potential herbicide contact time. In addition, dye-impregnated SRMDs were deployed in 0.4-ha plots and evaluated for their potential as slow-release herbicide carriers.

Dye dissipation data were used to calculate water-exchange half-lives in plots treated with conventional application techniques. Mean half-lives ranged from 8.8 to 12.2 hr in riverine plots, to 36.3 hr in a plot situated in a protected embayment. Half-lives from these 4-ha plots were two to four times longer than half-lives measured in smaller plots (0.4 ha) from previous dye studies conducted in similar locations. In most cases, dye release rates from SRMDs provided water concentrations near the target level of 10 µg/L through 7 days

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after deployment (DAD). Dye concentrations peaked at 105 to 130 µg/L at 2 DAD in Plot 1 (main channel plot) and 45 to 82 µg/L at 1 DAD in Plot 2 (side channel plot).

When compared with herbicide concentration/exposure time relationships developed in separate laboratory experiments, results from these studies suggest that endothall, 2,4-D, and triclopyr are potential candidates for controlling Eurasian watermilfoil in selected locations in the Pend Oreille and Columbia Rivers. When using conventional, liquid herbicide application techniques in these rivers, treatment sites should be a minimum of 4 ha in size. Results from the SRMD evaluations indicate that this slow-release carrier has potential for improving the control of Eurasian watermilfoil in high water-exchange environments, and a similar herbicide matrix should be evaluated in hydraulic channels and/or the field.