In cooperation with the U.S. Army Corps of Engineers

Site Fidelity, Habitat Associations, and Behavior During Dredging Operations of White Sturgeon at Three Tree Point in the Lower Columbia River.

U.S. Department of the Interior
U.S. Geological Survey

SITE FIDELITY, HABITAT ASSOCIATIONS, AND BEHAVIOR DURING DREDGING OPERATIONS OF WHITE STURGEON AT THREE TREE POINT IN THE LOWER COLUMBIA RIVER

Final Report to the

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Executive Summary

In 2001, the U.S. Geological Survey's Columbia River Research Laboratory began studies to address concerns about how dredging in the lower Columbia River for channel maintenance might influence sturgeon. These studies were funded by the U.S. Army Corps of Engineers, Portland District. Two specific objectives were addressed during field studies that ended in October 2003:

1) Determine if site fidelity or home ranges of juvenile and adult sturgeon are restricted to areas that may be affected by dredged material disposal in flowlanes, and
2) Monitor sturgeon behavior in flowlane disposal areas as dredged materials are added to describe short-term responses of fish to this activity.

Implicit within these objectives was the understanding that habitats important to sturgeon using these areas would also be identified.

Data on movements of 33 white sturgeon at Three Tree Point near river mile 30 were collected during a 14-month deployment of two types of acoustic telemetry systems. No green sturgeon were captured in the study area. A positioning system provided continuous monitoring of fish movements at intervals as short as 40 seconds. A series of individual data-logging receivers provided information on dispersal and migration from the study area.

Key findings were that:

- White sturgeon exhibited three types of movements – migration, dispersal, and localized within the study area.
- Localized movements over time by individuals and the return to previously occupied areas after seasonal migrations indicated a high degree of site fidelity for some individuals.
- Dispersal over short to medium time periods to adjacent areas by some individuals provided an opportunity for discovery of additional habitats.
- The majority of fish migrated to areas upstream of river mile 28 during winter months.
- White sturgeon did not disperse during pipeline dredging operations.
- White sturgeon did not disperse during hopper dredge disposal operations.
- Fish used a wide range of river depths and moved to shallower water at night.
- Fish preferred sloping areas of the riverbed over flat areas.
- Fish preferred riverbed areas with low to moderate bedforms.

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Contents

Executive Summary ii

Acknowledgements iii

1.0 Introduction 1

1.1 Background 2

1.2 Study Area 2

2.0 Methods 4

2.1 The telemetry array 4

2.11 Positioning System 4
2.12 Acoustic Data-logging Receiver Array 6
2.13 Acoustic transmitters 8

2.2 Fish Capture and Handling 8

2.3 Post-Processing Acoustic Data 9

2.31 VRAP 9
2.32 VR2 Receivers 12

2.4 Analyses 13

2.41 Site fidelity 13
2.42 Behavior during dredging operations 13
2.43 Habitat associations 15

3.0 Results and Discussion 15

3.1 Environmental conditions and other notable events during the study 15

3.2 Individual fish histories 18

3.2 Site Fidelity and Movements 19

3.3 Sturgeon behavior during dredging operations 22

3.31 Pipeline dredge operations 23
3.32 Hopper Dredge Disposal 27

3.4 Habitat associations 31

3.41 Depth 32
3.42 Riverbed slope 32
3.43 Riverbed roughness 33

4.0 Conclusions and Implications for In-river Work 34

5.0 Literature Cited 37

APPENDIX A. Speed of sound in water measurements obtained from August 2002 through September 2003 near Three Tree Point. 39

APPENDIX B. Accuracy Assessment of the Radio Acoustic Positioning System Deployed at Three Tree Point 40

Methods 40
Results 41
Discussion... 41
APPENDIX C. Pressure transmitter verification results. 45
APPENDIX D. Commercial fishing periods that occurred during this study. 49
APPENDIX E. Time periods when the VRAP system was not functioning. 51
APPENDIX F. Individual fish histories obtained during this study. 52

1.0 Introduction

White and green sturgeon (*Acipenser transmontanus* and *A. medirostris*) are known to inhabit areas within the lower Columbia River where dredging occurs. Questions have been raised regarding the affect of these dredging operations on habitat and movements of these fish (USACE 1999, Romano et al. 2002). Previous studies on habitat use and availability of habitat for white and green sturgeon (Parsley et al. 1993, Parsley and Beckman 1994, Erickson et al. 2002, Perrin et al. 2003) provide a general description of important habitats at a scale of hundreds to thousands of meters, but those studies were not intended to resolve site-specific habitats nor movements at scales of tens of meters. This resolution is needed to address dredging issues.

In addition to habitat issues, questions have been raised about the behavior of sturgeon during dredging activities. Dredging operations cause disturbance to water quality and the underwater environment in localized areas – turbidity, suspended sediment loads, and underwater noise associated with cutting and disposal operations increase above baseline levels. Avoidance behavior would result in fish moving away from the disturbance, whereas attraction would cause fish to move towards the disturbance. These behaviors are important at the individual and population levels, and can help fish survive in environments with variable conditions (Sullivan et al. 2003). A change in behavior may also have a negative population affect if it results in reduced individual growth or survival.

In 2001 the U.S. Army Corps of Engineers contracted with the U.S. Geological Survey's Western Fisheries Research Center, Columbia River Research Laboratory, to investigate how dredging operations may affect white sturgeon and green sturgeon habitat and behavior. The goal of the USGS work was to provide information that can be used to assist management of dredging operations in the lower Columbia River.

Two specific objectives were identified during the interagency coordination process. They were to:

1) Determine if site fidelity or home ranges of juvenile and adult sturgeon are restricted to deepwater areas that may be affected by dredge material disposal, and
2) Monitor sturgeon behavior in deepwater disposal areas as dredged materials are added to describe short-term responses of fish to this activity.

Implicit in these objectives was the understanding that habitats important to sturgeon found in areas where channel maintenance activities occur would also be identified.

A feasibility study in 2001 by the USGS (Parsley and Kirby 2001) showed that an array of acoustic telemetry data loggers and a positioning system could be deployed to collect data needed to address these objectives. Thus, this equipment was deployed in August 2002 and operated continuously until mid October 2003. Only movements of acoustic-tagged white sturgeon were monitored. No green sturgeon were encountered during this study; the study site was located at the extreme upper extent of their known range in the Columbia River. This report describes the telemetry array and data collection procedures used by the USGS, documents the data collected, and provides analyses and interpretation of the data as it applies to addressing the two objectives listed above. Additional analyses were also done to describe general behaviors of fish that became apparent during the study and to identify habitat associations.

1.1 Background

The U.S. Army Corps of Engineers conducts dredging in the lower Columbia River to maintain an authorized navigation channel. Dredged materials are placed in upland disposal sites, used to enhance beaches, or returned to the water. In-water disposal refers to the placement of dredged material along the riverbed in or adjacent to the navigation channel or in designated in-water sites. Commonly referred to as flowlane disposal, this disposal technique has been used in the Columbia River for many years during ongoing maintenance dredging activities. Flowlane disposal sites may move from year-to-year, depending on the dredging location and river depths available in the vicinity of the dredging action. Flowlane disposal must be placed within and adjacent to the navigation channel primarily in water depths from 45 to 65 ft (13.7 to 19.8 m) with some exceptions for disposal in depths as shallow as 35 ft (10.7 m) and as deep as 80ft (~25 m) (USACE 1999).

The U.S. Army Corps of Engineers dredges about 5 million cubic yards (3.8 million cubic meters) of sediment each year to maintain the navigation channel (USACE 1999). These activities occur throughout the lower river primarily in late spring through early fall. Hopper, pipeline, and clamshell dredges are used on the Columbia River with the former two completing most of the work. Hopper dredges can haul material several miles to a disposal site. During dumping, hopper dredges must maintain vessel speeds that enable steerage, thus with each dump the materials will be spread linearly along the riverbed. A single hopper dredge may typically make 8-10 dumps per day, resulting in aggradation of the riverbed in localized areas of 2 – 8 inches (5.1 – 20.3 cm) per dump. Pipeline dredges can pump dredged materials several thousand feet to disposal sites. Pipeline dredge operations differ from hopper dredge operations in that the cutting and disposal of dredged materials occur concurrently. During flowlane disposal the outlet for a pipeline dredge is moved periodically to avoid mounding. The outlet is typically located at a minimum depth of 20 ft (6.1 m). Pipeline dredging disposal operations can occur continuously for several weeks at a time at a given location. Sand, the major sediment type in the lower Columbia River, is heavy and settles relatively quickly. Therefore, turbidity from disposal of dredged materials is reported to be limited and transitory in nature (USACE 1999).

1.2 Study Area

A site near river mile 31 (river km 50) was selected as the location for the long-term deployment of telemetry receivers (Figure 1). The flowlane disposal site is largely within the delineated Federal navigation channel. Bathymetry of the area is varied and the thalweg holds close to the north (Washington) shoreline. While extensive shoals exist to the south of the navigation channel, a scour hole approximately 135 ft (34 m) in depth exists immediately downstream from the basalt outcrop that forms the cape called Three Tree Point (Figure 1).

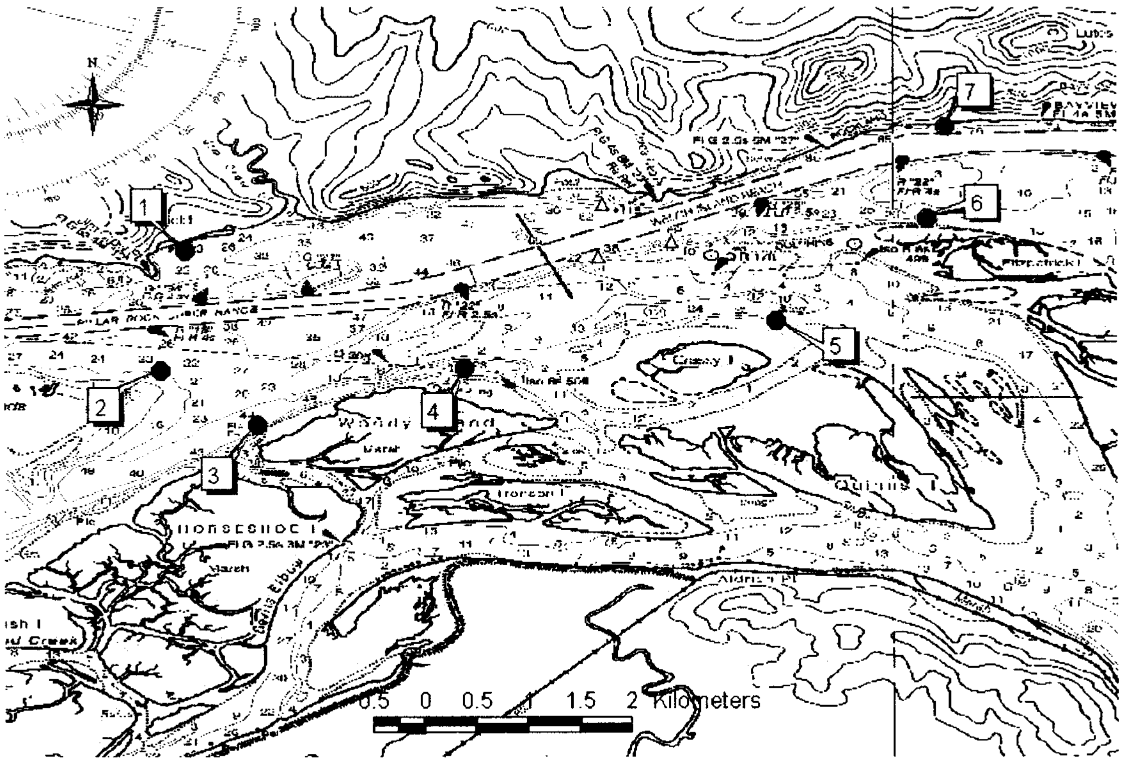

Figure 1. Placement of acoustic telemetry receivers. Circles with a corresponding number indicate locations of the VR2 data logging receivers and the triangles show the locations of the individual VRAP system buoys.

Prevailing river currents tend to push suspended and bedload material northward toward the Washington shoreline. This causes shoaling within the defined navigation channel that is removed, typically by a pipeline dredge, 2-3 times per year. The river floor in this area is comprised of fine to coarse sands. Substantial sand waves exist on the riverbed and are indicative of a high-energy environment.

Tide information from the NOAA tide station in Skamokawa, Washington (RM 34.5; 46°16.0'N 123°27.1'W) approximately 3 miles (4.8 km) upstream shows a mean tidal range of 6.12 ft (1.87 m) and a diurnal range of 7.57 ft (2.31 m). Because ocean tides are the main influence on water surface elevations downstream of river mile 40 (river km 64.4) the study site can experience current reversal caused by changing tides throughout seasonal periods of low to moderate river discharges. The study site is located at the extreme upper limit of saltwater intrusion.

The study site has substantial commercial and recreational water traffic. The federally authorized navigation channel bisects the site. Approximately 2,000 commercial deep-draft vessels transit the site each year (USACE 1999). The area is within the designated Commercial Fishing Zone 2. During commercial fishing seasons gillnets are frequently drifted through the area. The area is also a popular spot for recreational sturgeon angling.

2.0 Methods

2.1 The telemetry array

The USGS used two independent telemetry systems to collect data on fish movements and depths over time. An acoustic positioning system provided detailed information on fish movements within a localized area, while 7 acoustic data loggers located primarily upstream and downstream of the positioning system (Figure 1) provided information about direction of fish that departed the center of the study area and gave a longer record of depths used by fish. The telemetry array components were put in place, tested, and fully operational by mid August 2002. These systems are described below.

2.1.1 Positioning System

A Vemco radio-acoustic positioning (VRAP) system was used to collect individual fish position data. It was comprised of 1) three moored buoys each with a hydrophone, an acoustic receiver, and a radio modem, and 2) a shore-based processing center composed of a base station and a computer (Figure 2). Acoustic signals from fish carrying ultrasonic transmitters were received at each buoy then transmitted via radio transceivers to the base station. The VRAP system software running on the computer then calculated the x and y coordinates of the transmitter based on hyperbolic equations and time of arrival of acoustic signals at each hydrophone. These x and y coordinates are relative to the center of the triangular buoy array. Klimley et al. (2001) provides a thorough description of theory and operation of the VRAP system. Real-world geographic coordinates of each buoy position were repeatedly checked using GPS receivers operating the Precise Positioning Service[1]. The vendor-provided software transformed the VRAP derived x and y coordinates to real-world geographic coordinates through use of a geo-referenced raster image. These spatial coordinates were used for display and analysis within a geographic information system.

Each buoy was independently moored with two anchors, one upstream and one downstream, to minimize buoy drift. An internal 12-volt battery powered each buoy and voltages were continuously displayed on the base station computer. A fourth buoy, kept on a charger on shore, was rotated into the array when the voltage of a functioning buoy dropped below 11 volts. Experience showed that buoys were able to function at voltages greater than 9.5 volts.

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[1] Precise Positioning Service (PPS) is available to the military and certain Federal civilian agencies. This service differs from the Standard Positioning Service available to civilian users. The GPS receiver incorporates the Wide Area GPS Enhancement (WAGE) system and can achieve less than 4 m error in horizontal positioning autonomously in real-time without the need for broadcast variables or post-processing. The WAGE also provides position error estimates to indicate the quality of the data.

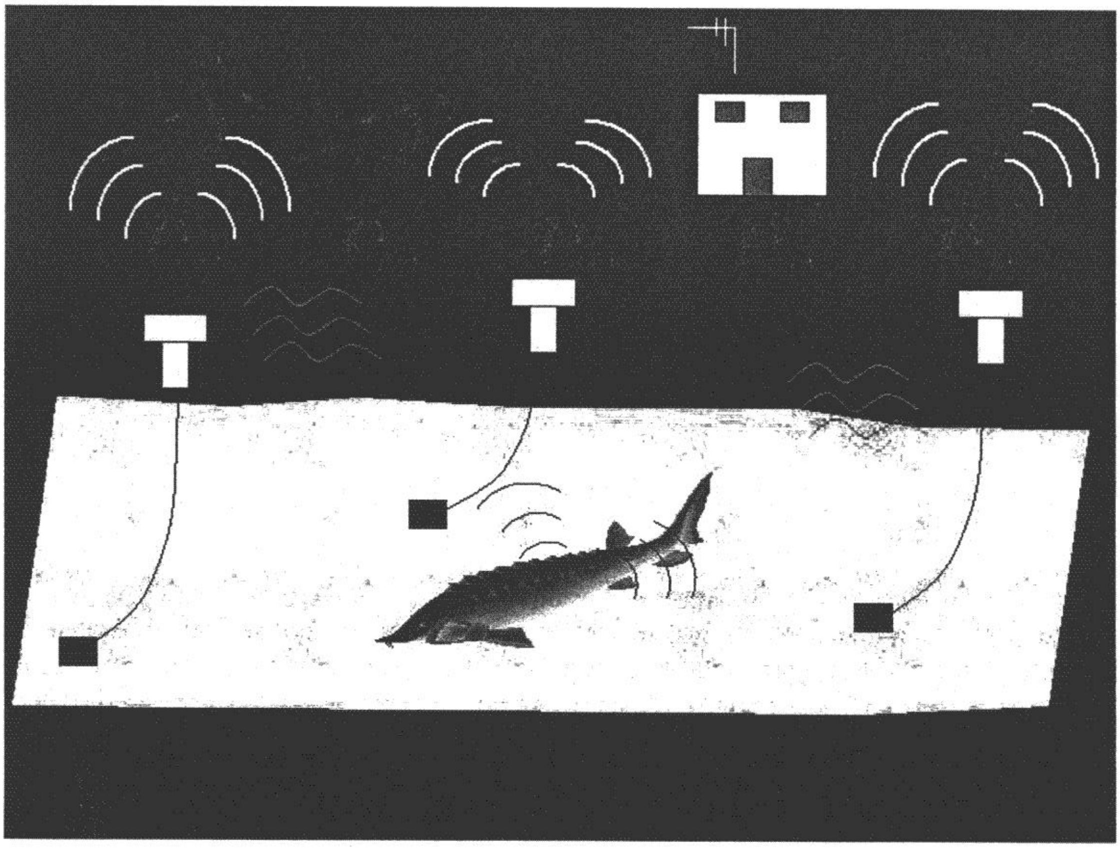

Figure 2. Elements of the Vemco Radio Acoustic Positioning (VRAP) system incuding three moored bouys with hydrophones and radio modems, a shore-based radio modem and data processing computer, and a fish carrying an acoustic transmitter. Graphic is not drawn to scale.

The base station and data processing computer was located approximately 2 miles (3 km) upriver near the town of Skamokawa, Washington. Initially, an omnidirectional radio antenna supplied by the vendor was used for radio signal transmissions between the base station and the buoys. To reduce sporadic radio communication failures between the base station and the buoys, a directional antenna was installed during the winter.

Positioning of acoustic transmitters by the buoy array relied on synchronized clocks among system components. The base station updated the clocks of the buoys and received stored acoustic data from the buoys at three-minute intervals. The base station obtained real-world time from the computer's clock. Analyses comparing fish positions with dredge positions required synchronization of clocks as well. It became apparent that the minor drift inherent in the internal clock of the computer, while not detrimental to the accuracy of calculated fish positions, would cause difficulties in comparing time series data from different sources (e.g. dredge activities). Highly accurate time is available in GPS signals, and GPS time is used by ships including the dredges operated in the lower Columbia River. Therefore, an external clock that used timing available in GPS signals was installed on the computer. This clock updated the computer clock every 60 seconds.

To provide a means of checking to see if buoys had moved due to currents or other factors, the VRAP system performed a self-calibration of distances between buoys every three hours. Buoys emitted and received acoustic signals and determined separation distances using speed of sound in water. In addition, a periodic check of real-world coordinates of the individual buoys was made with a GPS receiver when maintenance was performed on the buoy array.

Speed of sound in water is needed to accurately calculate the position of a transmitter and to calculate buoy separation distances. We used a Smart CTSV manufactured by Applied Microsystems Limited of Canada to directly measure this parameter. The Smart CTSV has a stated sound velocity accuracy of <0.06 m/s and a temperature accuracy of +/- 0.005 °C. Sound velocity was measured periodically within the VRAP buoy array by lowering the Smart CTSV approximately 3 m into the water column. The sound velocity measurement was rounded to the nearest whole number and input into the project settings of the VRAP software (Appendix A).

Horizontal accuracy of the positioning system is best within the triangular array, and decreases with increasing distance. Positioning accuracy and acoustic signal reception are highly dependent on local conditions. Relative performance of the positioning array was assessed through a series of tests that drifted acoustic tags through the array on drogues. This testing is described in Appendix B. Basically, ultrasonic tags were attached to a weighted rigid pole extending approximately 12 ft (4 m) below the drogue. The drogue carried a survey grade GPS receiver operating in real-time kinematic processing mode that provided drogue positions accurate to within 4 inches (10 cm) every second. Drogue tracks from the positioning array and the GPS receiver were then compared.

The level of positioning accuracy required is dictated by the individual study objectives; greater accuracy is needed for objectives where metrics such as rates of movements are needed, whereas substantial inaccuracy can be acceptable for meeting objectives requiring information on presence or absence (e.g. site fidelity). As described below, a series of filters were implemented during post processing to maximize data available for analyses while ensuring adequate accuracy for specific objectives.

2.1.2 Acoustic Data-logging Receiver Array

Seven Vemco VR2 submersible acoustic receivers were placed to act as gates around the positioning system (Figure 1). The receivers were located to provide additional information about fish that moved beyond the range of the positioning system. They recorded the time and date of acoustic signals received and the individual identification number as well as depth of the fish with transmitters that had depth-sensing capabilities. The receivers were submersible single channel data loggers that operated on a single frequency (69 kHz). The receivers were housed in a cylindrical PVC case with an integral hydrophone on one end. An internal lithium battery allowed them to operate autonomously for up to 8 months. The information was stored in Flash memory until downloaded onto a computer via a VR2-PC Interface and vendor-supplied software. The receivers were generally deployed on moorings in water depths of approximately 25-35 ft (7.6-10.7 m) at low tide. Each receiver was suspended approximately 14 ft (4.5 m) below the water surface with the hydrophone oriented downward. The geographic locations and method of deployment of these receivers varied during the study to minimize conflicts with commercial fishermen and because of loss of receivers due to unknown causes. Data from each receiver was downloaded opportunistically, but generally occurred every 4-8 weeks.

After deployment of the receivers, commercial fisherman immediately voiced concern that the moorings would interfere with their traditional gillnet drifts. As a concession to their concerns, the USGS agreed to remove the data loggers from the river during commercial fisheries, but would leave the positioning array. While this action had the potential to reduce the information collected on movements away from the positioning array, it was deemed a reasonable compromise against potential loss of gear that was suggested would occur. The seven data loggers were removed from the river on 15 September 2002 and redeployed on 12-13 November 2002. Relations improved with commercial fisherman during the course of the study and no data loggers were removed during 2003 commercial fishing periods. The physical location of several data loggers was altered slightly to better accommodate the commercial fishermen.

Loss of acoustic data loggers did occur at two locations due to unknown causes. Replacements were redeployed when the loss was noted. The loss of receivers and removal of receivers during commercial fisheries resulted in temporal and spatial gaps in the data expected to be collected at the receiver locations (Table 1).

Table 1. Gaps in data collection at VR2 receiver sites caused by lost receivers. All receivers began collecting data in August 2002.

VR2 receiver site	Dates when no data was obtained
1	16 September – 12 November 2002
2	16 September – 11 November 2002
	13 February – 14 October 2003
	Note: due to persistent loss of receivers at this location during February and March 2003, the site was abandoned. Sites 1 and 3 provided coverage for this area as well.
3	16 September – 11 November 2002
	30 September – 14 October 2003
4	16 September – 11 November 2002
5	16 September – 12 November 2002
6	16 September – 11 November 2002
7	16 September – 12 November 2002

2.1.3 AcousticTransmitters

Two types of individually identified coded ultrasonic tags were used in this study: pingers, which conveyed identification information only, and telemetry transmitters which also conveyed pressure (converted to depth) that the tag was exposed to. The standard pinger tags were smaller than pressure tags, and therefore were used in smaller fish. All tags operated at 69 kHz. Vemco model V8SC-2H pingers were 30 mm in length, 9 mm in diameter and weighed 3.1 g in water. These tags had a specified operating life of 234 days. Vemco model V16-4HP pressure tags were 80 mm in length, 16 mm in diameter and weighed 12 g in water. These tags had a specified operating life of 734 days. All tags typically operated longer than the vendor-specified longevity.

Prior to use, each tag was dipped in beeswax, a biologically inert compound, and tested to ensure proper operation. Pressure tag functionality was verified prior to use by suspending tags at known depths (Appendix C).

The transmitters emitted a unique coded pulse train followed by a random length interval of 60 – 180 seconds for the smaller tags and 40 – 114 seconds for the larger pressure tags. The random repeat interval provided several functions – it increased the longevity of the tags and optimized opportunities for decoding numerous tags all operating at 69 kHz. That is, in the acoustic environment where collisions of acoustic signals caused by multiple tags firing at the same time was expected, randomizing the timing of the individual tags maximized the probability of decoding individual tags.

2.2 Fish Capture and Handling

Baited setlines were fished to capture sturgeon. Fishing effort occurred within or adjacent to (< 100 m outside) the triangle formed by the three VRAP buoys. Each setline typically consisted of a 300 ft (91.5 m) mainline, a claw anchor at each end of the mainline, anchor lines adjusted to local conditions, inflatable surface buoys that attached to the anchor lines, and 20-30 circle hooks. Circle hooks of size 12/0, 14/0, and 16/0 were used during all sets. Each hook was rigged as part of a gangion that could be easily clipped and unclipped from the mainline. Hooks were attached to the mainline at approximately 10 ft (3 m) intervals. Pickled squid was used as bait on all setlines except for four lines set in February 2003 when fresh smelt was used. Setlines were generally set parallel to, but not within, the Federal navigation channel. Setlining occurred between August 2002 and July 2003 as needed. Most setlines were set overnight, but soak times varied between 8 and 20 hours in duration.

We altered our efforts (e.g. number of lines set, number of hooks per line) depending on site conditions and target number of fish to be caught. Many small white sturgeon were immediately released when brought on board because they did not meet minimum size requirements for implanting ultrasonic tags. Sturgeon that were good candidates for tagging (appropriate minimum length and in good condition) were held on board the vessel in a large galvanized tub. Only white sturgeon were captured during setlining and no mortalities occurred.

Six white sturgeon were implanted with V8SC-2H transmitters and 27 white sturgeon were implanted with V16-4HP transmitters during August 2002 and April-July 2003 (Table 2). The transmitters were surgically implanted into fish meeting minimum length requirements. After measuring fork length and total length, individual fish were placed ventral side up in a V-shaped trough lined with foam. A small pump attached to a hose moved river water gently over the gills during surgery. An incision approximately 40 mm long was made with a surgical scalpel along the mid-ventral line about 50 – 70 mm anterior to the insertion of the pelvic fins. Forceps were used to spread the musculature apart and the transmitter was inserted into the abdominal cavity. Incisions were closed by four to five interrupted sutures with 2-0 or 4-0 coated PDS II (Ethicon coated Vicryl or Visorb, a generic of Vicryl). Surgical gloves and scalpels were changed between surgeries and tools were kept in Betadine when not in use. Betadine was also applied to the closed incision to reduce infections. Fish were released near the capture site.

2.3 Post-Processing of Acoustic Data

2.3.1 VRAP System

All raw acoustic data received from the buoys was automatically stored on the base station computer. This raw data was periodically burned to a CD and archived. Processing the raw acoustic data prior to analyses required several steps. First, the vendor-supplied software (VRAP version 5.1.4) was used to generate ASCII files of all fish position data and depths, and buoy calibrations. Here, the coded detection threshold for fish positions was set at high, resulting in a database consisting of what the software considered to be only high quality fish positions. This filter refers to the minimum number of pulses required from a coded tag in order to consider a position valid. To calculate a position, one buoy must receive a complete coded pulse train to identify the tag (ID code) but the number of pulses received by the other two buoys to plot a position may be varied. The high setting required that for each fish position, one buoy received all eight pulses of the pulse train and the other two buoys received the sync code plus 3 additional pulses. The resulting ASCII file was then imported into a spreadsheet for further formatting. Here, column headings were added, geographic coordinates were converted to decimal degrees, and the spreadsheets were converted into an Access® database.

Further filtering prior to analyses was then performed. Data for individual fish within two weeks after tagging was eliminated to remove positional data that may have been influenced by capture and tagging. Two transmitters ceased moving within the array after variable periods at large. Positions after movement ceased were removed from the database.

Table 2. Characteristics of 33 white sturgeon tagged within the study area (19 during 2002 and 14 in 2003).

Date	Tag type	Tag ID	FL (cm)	TL (cm)
14-Aug-02	V16-4HP	5	90	102
14-Aug-02	V16-4HP	6	105	119
14-Aug-02	V16-4HP	8	84	95
14-Aug-02	V16-4HP	9	98	109
14-Aug-02	V16-4HP	10	97	108
20-Aug-02	V16-4HP	7	106	118
20-Aug-02	V16-4HP	11	101	115
20-Aug-02	V16-4HP	13	85	97
20-Aug-02	V16-4HP	14	82	94
20-Aug-02	V16-4HP	17	82	94
20-Aug-02	V16-4HP	18	86	100
20-Aug-02	V8SC-2H	251	58	66
20-Aug-02	V8SC-2H	252	50	58
20-Aug-02	V8SC-2H	253	66	76
21-Aug-02	V16-4HP	15	122	137
21-Aug-02	V8SC-2H	255	55	62
22-Aug-02	V16-4HP	12	112	127
22-Aug-02	V16-4HP	16	107	123
22-Aug-02	V16-4HP	19	100	110
22-Apr-03	V16-4HP	20	93	106
22-Apr-03	V16-4HP	21	88	100
22-Apr-03	V16-4HP	23	76	88
22-Apr-03	V16-4HP	25	117	132
22-Apr-03	V8SC-2H	256	51	55
6-May-03	V16-4HP	22	95	107
6-May-03	V16-4HP	24	86	97
6-May-03	V8SC-2H	254	56	64
29-Jul-03	V16-4HP	26	110	127
29-Jul-03	V16-4HP	27	114	127
29-Jul-03	V16-4HP	28	85	98
29-Jul-03	V16-4HP	29	98	109
29-Jul-03	V16-4HP	30	111	124
29-Jul-03	V16-4HP	31	81	92

Shadow zones are wedge-shaped areas at the corners of the triangle formed by the buoy array where the position calculation of a transmitter will have two solutions. Fish locations within shadow zones were not used in analyses requiring positions. Depths reported from tags within shadow zones were still valid.

Occasionally the buoy calibration sequence would fail and the software would continue to calculate erroneous fish positions until the next buoy calibration cycle. Plotting all calibrated buoy positions in ArcView 3.3 and noting time periods when calibrations were wrong identified these time periods. Typically, buoys moved in a predictable tight array due to variation in currents and tides. Erroneous buoy positions were readily identifiable (Figure 3) and fish positions collected during the three-hour block of time until the next calibration were eliminated from analyses requiring position data. Depths reported from erroneously positioned tags were still valid.

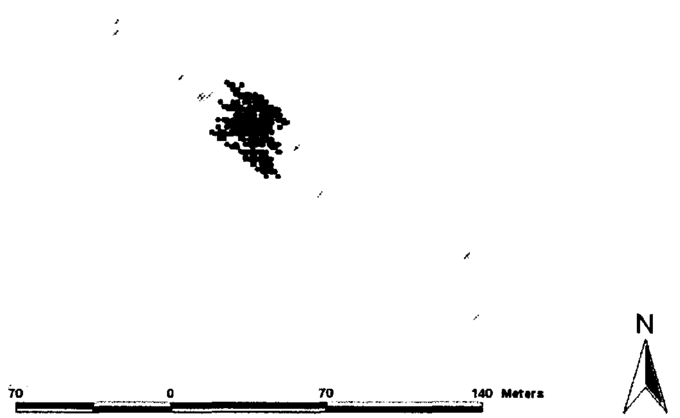

Figure 3. Example of calibrated buoy positions for one buoy showing accurate positions (black dots) and inaccurate positions (light x's). Fish positions obtained during 3-hour time periods when the buoys were not calibrated correctly were eliminated. Slow rates of buoy creep due to tides and currents are evident. This movement was accounted for each time a geographic coordinate was obtained for each buoy.

As determined by testing (Appendix B), calculated positions located more than 900 m from the center of the VRAP array contained a high degree of error. For analyses requiring accurate position data, all positions located greater than 900 m from the center of the array were removed by clipping the data within a 900 m radius in ArcView.

As a final filter to remove erroneous fish positions conceivably caused by multi-path acoustic signals and other factors, a maximum rate-of-movement filter was applied. The successive distances between fish positions for each individual fish were calculated in ArcView and divided by the time between successive locations to determine a rate of movement. All positions with associated rates of movement of greater than 4 m/s were removed from the data set. A plot of final fish positions after applying these filters is shown in Figure 4.

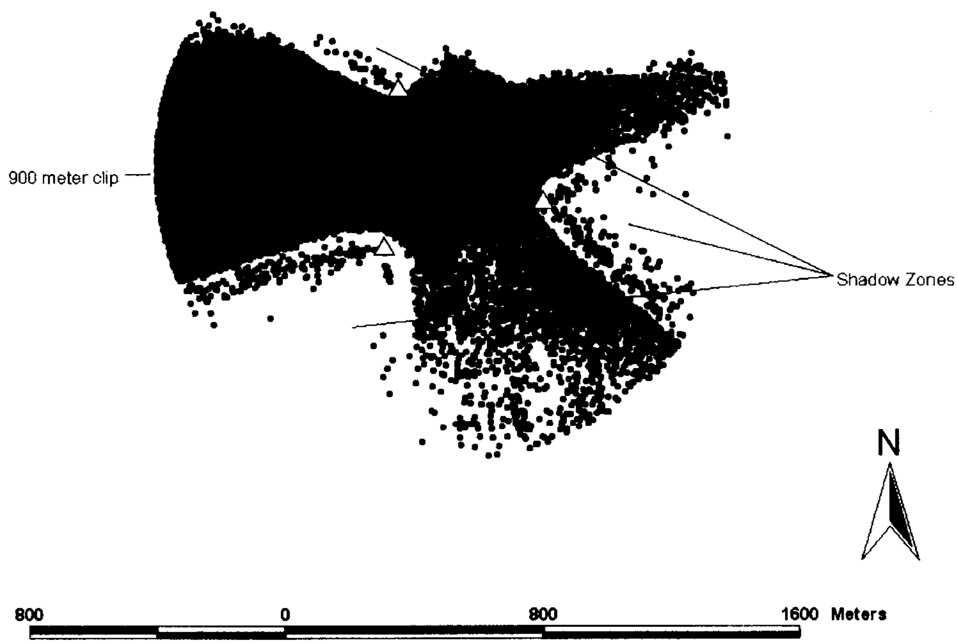

Figure 4. Plot showing all filtered fish positions. Shadow zones are the areas behind each buoy (shown as triangles), and the 900 m radius filter is also apparent.

Each filter described above created a new table within the Access® database. These tables allowed specific sets of data to be extracted and exported for analysis using other software as needed.

2.3.2 VR2 Receivers

Acoustic tag data downloaded from the VR2 receivers was placed into an Access® database with the appropriate field headings (date, time, tag code, and depth, if the tag was a sensor tag). No additional processing was done to this data.

2.4 Analyses

2.4.1 Site Fidelity

Analysis of site fidelity explores spatial locations of animals over time. Three general types of movement are associated with site fidelity: 1) migration, 2) dispersal, and 3) localized movement (Kernohan et al. 2001). White and Garrott (1990) defined migration as a regular, round-trip movement of individuals between two or more areas or seasonal ranges, whereas dispersal is one-way movement of individuals from their natal site or an area that has been occupied for a period of time. Localized movements describe the daily movement patterns of an individual, often within a home range.

Individual and group behaviors were used to evaluate site fidelity at Three Tree Point. The study area encompassed an unknown portion of the actual multi-year home range of sturgeon, so fidelity of sturgeon at Three Tree Point was explored on a more general level instead of statistically. Fish histories that describe time spent in the VRAP array, movements to the VR2's, and time periods when fish were not detected at all were used to qualify migration and dispersal. Localized movements within the positioning array were explored in ArcView.

2.4.2 Behavior during dredging operations

During the long-term deployment of the VRAP array three separate dredging operations occurred within the detection radius of the array. These included two pipeline dredging events and one hopper dredge disposal operation. Data on fish movements collected before, during, and after these events was used to characterize short-term response by white sturgeon. Metrics included emigration, immigration, movement, and depth use. Spatial analyses of density plots to investigate shifts in focal areas during short periods before and during each dredging operation were also conducted.

The Animal Movements Extension for Arc View 3.3 (Hooge et al. 1997) was used for spatial analyses. Fish location data were filtered as described above and reprojected into North American Datum 1983 (NAD 83) zone 10. Kernel density estimates, describing the utilization distributions of sturgeon individuals and groups, were built and compared within each dredging operation. The kernel method places a probability density over each observation point in the sample (Seaman and Powell 1996). This method is free of parametric assumptions and provides means of smoothing location data (Worton 1989). Fixed kernels were used with the least squares cross validation for the smoothing factor. Kernels were used to describe density shifts in relation to dredging areas. The Animal Movements Extension was used to describe movement paths for individual fish.

2.4.2.1 Pipeline Dredging Operations

The Port of Portland's pipeline dredge, the Oregon, has been tasked to the Three Tree Point area generally once per year to clean up a cutline shoal on the south side of the navigation channel adjacent to and extending downriver from the area where the VRAP array was deployed. In 2002, the Oregon operated in this area from September 19 through October 2, with ten days of operations and four weekend days of inactivity. In 2003, the Oregon worked the same area during June 25 through July 10 with nine days of operations and 6 weekend and holiday days of inactivity. During both years, the pipeline outlet was routed so disposals occurred within the area monitored by the VRAP array.

Analyses of fish behaviors before, during, and after pipeline dredging operations were confounded by the inactive periods that occurred during the dredging operations in both years. Attraction or repulsion by dredging operations was determined by investigating fish movements during the first 24 hours of dredging activity. A repeated-measures (with individual fish as the repeated variable) analysis of variance (ANOVA) was used to test for differences in movement and depths of individual sturgeon among periods of equal time before and during dredging. Movement and depth variances were heterogeneous so a mixed model was used (proc MIXED in SAS; Littell et al 1996). For 2002, fish movement data during the two-week block of time before the dredging operation began (September 6 to September 19) was compared to movement data during the two-week period when the dredge was working (September 19 to October 2). For 2003, fish movement data during the one-week prior to dredging (June 18 to June 25) was compared to movement data during the first week of dredging operations (June 25 to July 2) since the pipeline dredge operations ceased for several days for the 4th of July holiday.

2.4.2.2 Hopper Dredge Disposal Operations

In May 2003, the hopper dredge Essayons was tasked to perform disposal operations within the VRAP array to investigate white sturgeon response. The Essayons removed materials near river mile 29 (river km 46.5) and during a 24-hour period made 12 distinct disposals within the VRAP array. The USGS was in contact with the Essayons during the disposal cycle and received detailed logs of the timing and location for each of the 12 disposals.

Analysis of fish movement data during this disposal operation differed somewhat from analyses of movements during pipeline operations because the hopper dredge operations were distinct instead of continuous. Attraction or repulsion was evaluated for the entire cycle (24 hrs). White sturgeon movement and depths were compared among three 24 h blocks of time: before, during, and after the disposal cycle. When there was a significant difference in the ANOVA, a least squares means procedure was used to identify where those differences occurred. In addition, the discrete nature of each disposal operation enabled an analysis of fish movements immediately before and immediately after each dump. A repeated-measures ANOVA was used to compare fish movement and depths among 20 min before disposal and 20 min after disposal blocks of time. Disposal start and end times were obtained from the Essayons logbook. Data on fish movements during the actual disposal events could not be obtained due to acoustic noise produced during the dumps. A Mann-Whitney test was used to compare the distances from individual fish locations to the disposal site for the 20 min period before disposal to the 20 min period after disposal to see if there was an attraction, repulsion, or no change in distance from the disposal area (proc NPAR1WAY in SAS). The

Animal Movements Extension (Hooge et al.1997) distance analysis tool was used to calculate sturgeon location distances from the area encompassing the 12 disposals.

2.4.3 Habitat Associations

The fish location data provided the opportunity to investigate habitats used by fish within the Three Tree Point study area encompassed by the positioning array. Habitats associated with fish locations were identified by frequency analysis. Relative importance of habitats was further ascertained by calculating the density of fish locations per unit area of each habitat descriptor. Compositional analyses or other methods of describing resource use by animals are not particularly suited to this data because the study area did not encompass the entire home ranges of white sturgeon in the lower Columbia River. However, knowledge of how sturgeon used the habitat in this localized area can be used to better understand how modification of the area by the addition of dredged materials may influence habitats associated with sturgeon use. Plots of the density of fish locations within habitat categories provide an assessment of important habitats.

Fish locations used in these analyses were those filtered as described above. Data were pooled across individuals and time. Because the number of observations among individuals varied, subsampling of the locations for individuals with more than 3,000 detections was performed to reduce bias towards those individuals with a large number of detections. After subsampling the database, over 27,000 fish locations still remained for analysis.

Detailed bathymetry of the study area was provided by the Army Corps of Engineers. This point data was imported into ArcGIS® and a raster surface (grid) was interpolated using a 10 m cell size. Spatial analyses were then done to describe fish location associations with river depths, riverbed slope, and rate of change of slope, or bottom ruggedness. This latter habitat descriptor characterizes river bedforms such as sand dunes or other bottom irregularities. It was derived by performing a nearest neighbor analysis on slope using a radius of 30 m. In essence, this provides a standard deviation of riverbed slopes over a 30 m distance; greater deviation implies a greater degree of bottom topography. Preliminary analyses using a radius of 10 m, 30 m, 50 m, and 100 m showed that dominant bottom features such as sand dunes were best captured using a 30 m radius.

3.0 Results and Discussion

3.1 Environmental conditions and other notable events during the study

Environmental conditions reported from the Beaver Army Terminal (USGS National Water Quality Network site 14246900) provide a general description of river conditions during this study. The Beaver Army Terminal is located approximately 24 miles upstream of the study site. Columbia River flows measured at Beaver Army Terminal were declining at the onset of the study in the fall of 2002 and began erratically increasing during winter (Figure 5). Flows were relatively stable during the spring runoff period and then declined sharply during the latter part of June 2003. Flows remained relatively low at around 2,000 – 4,000 m^3/s from July through mid October when the study was stopped.

River water temperatures were at their highest during the onset of the study and declined throughout the fall, sometimes precipitously, with the lowest temperatures occurring during January – March 2003 (Figure 6). Temperatures began rising in March 2003 and reached summertime highs in July and August.

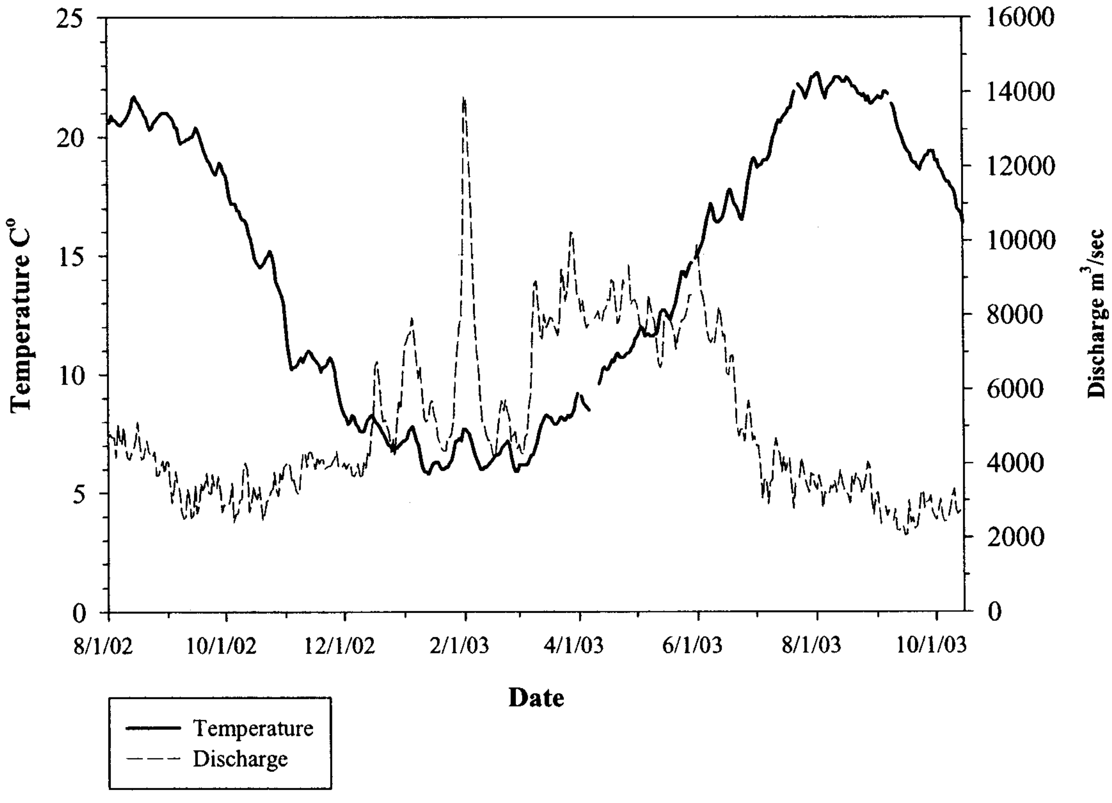

Figure 5. Mean daily river temperature and discharge measured at Beaver Army Terminal from August 1, 2002 to October 15, 2003. Beaver Army Terminal is approximately 24 miles upstream from the study site.

Turbidity measurements recorded at the Beaver Army Terminal show that while baseline river turbidities are relatively low (< 10 NTU) sharp increases and decreases did occur during the winter and spring (Figure 6).

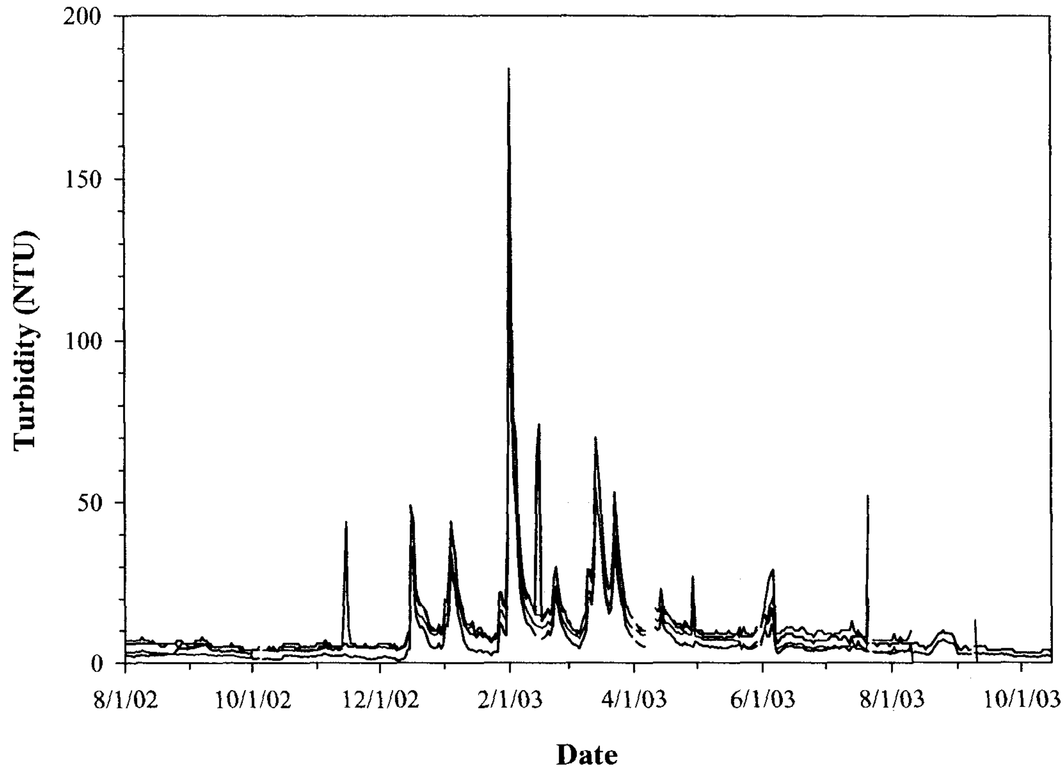

Figure 6. Median turbidity values recorded at Beaver Army Terminal from August 1, 2002 through October 15, 2003. The monitoring site reports turbidity measurements from 4 probes.

While these environmental conditions are indicative of general river hydrologic conditions at the study site, they do not necessarily reflect localized conditions at Three Tree Point caused by varying tides. For instance, plots of river discharge imply constant downstream direction to river currents. However, flow reversal commonly occurred during high tides when discharges were low, and there were short periods of negligible current velocities during slack tides. It was not an objective of this study to resolve these localized spatial and temporal differences in environmental conditions.

Thirty-six commercial fishing periods of various durations occurred during the study (Appendix D). As mentioned in the methods, the seven acoustic data loggers were removed from the water during fall 2002 fishing periods, but the positioning array remained in place. It is not known if commercial fishers drifted gillnets through the positioning array.

3.2 Individual fish histories

Automated collection of fish positions began immediately upon release of the first tagged white sturgeon into the study area on 14 August 2002. The positioning system was maintained in place until 14 October 2003. Typically, the system was intentionally shut down once or twice a week for less than three hours to perform routine buoy maintenance. However, the automated monitoring was unintentionally disrupted on several occasions for variable periods (Appendix E) due to various reasons including radio frequency interference and software or firmware malfunctions exacerbated by sporadic radio communication failures between the base station and one or more buoys.

Nineteen white sturgeon were tagged and released between 14 - 22 August 2002. A twentieth ultrasonic tag failed to function and was returned to the vendor for replacement. No further attempts were made to capture additional sturgeon for release during 2002.

Additional ultrasonic tags were purchased in January 2003 and efforts were made to capture more white sturgeon. None were captured on setlines fished during January, February, and March 2003. Catches resumed in April when five white sturgeon were tagged and released, followed by three in May and six in July. These latter fish were captured and released in anticipation of a scheduled hopper dredge disposal operation that was conducted as part of this study.

During the course of the study (August 2002 – October 2003) the total number of detections of individual fish by the positioning array and the gates varied from hundreds to tens of thousands (Table 3). The database for analysis after applying the various filters to ensure the best quality positional data contained 162,565 individual geographic coordinates of fish positions and 293,991 individual detections at the gates. As expected, data on individual fish was collected at highly variable intervals due to movements of fish in and out of detection ranges, local spatial and temporal acoustic conditions around the receivers, the random repeat intervals of the individual tags, and acoustic signal collisions.

Individual fish histories compiled by combining data from all acoustic gates and the positioning array are presented in Appendix F. Individual behaviors are readily apparent in the data. The histories give a visual sense of spatial and temporal patterns of movement. For example, one fish (ID 6) was not detected immediately after release within the positioning array, but obviously quickly moved upstream because it was detected at the two acoustic receiver gates for a brief period on the day that it was released. It then disappeared from our network of acoustic receivers until 19 September when it entered the positioning array and remained there for an extended period.

Other behaviors became apparent. Fish generally made diurnal movements to shallower water at night than they occupied during the day. This is visually apparent in the data and a mixed model (proc MIXED in SAS) confirmed that white sturgeon were deeper during 1000 hrs – 1400 hrs than they were during 2200 hrs – 0200 hrs ($P<0.0001$; Table 4). Some fish moved into relatively shallow water at night (i.e. < 5m deep; e.g. ID 6). Other fish exhibited a similar diurnal pattern of movement, that is they moved to water less deep at night, but they were still relatively deep (i.e. > 10 m deep: e.g. ID 11).

3.2 Site Fidelity and Movements

Three general types of movements of white sturgeon were recorded during this study – migration, dispersal, and localized movements. All fish tagged in the fall of 2002 departed the reach by late November, were absent all winter, and most then returned during April 2003, illustrating migration. Many sturgeon remained within the 4-mile (6.4 km) reach of river covered by the telemetry arrays for extended periods, illustrating dispersal. Localized diurnal movements to specific areas or depths were also apparent and confirmed local fidelity.

Of the 19 fish tagged during August 2002, 16 used the area for an extended period of time, 1 left the area two days after tagging and was not detected again, and 2 fish ceased moving within the VRAP array, indicating that they died or expelled their tag (Table 3). Fifteen sturgeon dispersed from the river reach during September and November and returned to the area in April and May 2003. The VR2 receivers were removed from the water during the fall of 2002 to accommodate commercial fisheries, so direction of dispersal was not known. However, VR2 receivers were in place during 2003 when fish returned to the area and the data show that 13 sturgeon returned to Three Tree Point from upstream. Therefore, the majority of sturgeon tagged during the fall at Three Tree Point wintered somewhere upstream of Three Tree Point. The two fish that returned to the area from downstream were smaller fish less than 100 cm total length.

Sturgeon tagged during April and May 2003 were captured during the period when fish were migrating through the area. Eleven of the 12 sturgeon tagged during 2003 departed downriver within one month after tagging. Seven remained at Three Tree Point for less than two weeks, four remained less than one month, and one remained within the telemetry array through the completion of the study. This illustrates that the river reach was a migratory corridor. Sturgeon tagged in 2003 may have been intercepted on their way downriver to a summering location. Many of these fish then returned and were monitored for brief periods of time in August, September, and October as they passed up river (Appendix F) indicating similar migration timing to the sturgeon tagged in 2002.

Table 3. Number of times individual fish were detected by the positioning system and the data logging receivers, and last known detection date and location.

Fish	Date	Number of detections by acoustic receiver system by year						
		Positioning array			Data loggers			
ID	tagged	2002	2003	Total	2002	2003	Total	Fate
5	14-Aug-02	4474	6755	11229	2623	25344	27967	Last detected 6 October 2003 1:47:23 AM at VR2 4 (downstream)
6	14-Aug-02	13053	0	13053	927	12	939	Last detected 30 June 2003 2:08:13 PM at VR2 6 (upstream)
7	20-Aug-02	1576	4224	5800	3067	3289	6356	Last detected 7 September 2003 1:38:56 PM at VR2 7 (upstream)
8	14-Aug-02	255		255	2431		2431	Determined to have died or shed tag on 16 September 2002
9	14-Aug-02	552	4234	4786	7487	32081	39568	Last detected 22 September 2003 1:09:49 PM at VR2 7 (upstream)
10	14-Aug-02	78	228	306	404	23069	23473	Last detected 16 September 2003 5:06:36 AM at VR2 3 (downstream)
11	20-Aug-02	6070	7616	13686	1122	3124	4246	Last detected 7 June 2003 9:16:57 AM at VR2 4 (downstream) Harvested by angler 6/7/2003, tag returned to USGS
12	22-Aug-02	242	0	242	715	0	715	Last detected 24 August 2002 1:50:36 PM at VR2 7 (upstream)
13	20-Aug-02	1134	0	1134	1634	180	1814	Last detected 30 July 2003 4:38:17 PM at VR2 7 (upstream)
14	20-Aug-02	5470		5470	497		497	Determined to have died or shed tag on 22 October 2002
15	21-Aug-02	2852	547	3399	1660	614	2274	Last detected 20 April 2003 12:54:44 PM in VRAP array
16	22-Aug-02	835	1971	2806	4905	33579	38484	Last detected 8 September 2003 10:46:41 AM at VR2 7 (upstream)
17	20-Aug-02	5622	37659	43281	1805	12655	14460	Present at end of study 14 October 2003
18	20-Aug-02	360	2194	2554	460	21513	21973	Last detected 16 September 2003 4:05:38 AM at VR2 7 (upstream)
19	22-Aug-02	2527	1969	4496	4370	247	4617	Last detected 27 April 2003 12:22:27 AM at VR2 6 (upstream)
20	22-Apr-03		2775	2775		9125	9125	Last detected 12 October 2003 4:59:01 AM at VR2 7 (upstream)
21	22-Apr-03		377	377		10574	10574	Last detected 24 June 2003 12:29:08 AM at VR2 3 (downstream)
22	6-May-03		680	680		6196	6196	Last detected 16 June 2003 1:25:16 PM in VRAP
23	22-Apr-03		4885	4885		4481	4481	Last detected 2 June 2003 5:08:44 AM at VR2 3 (downstream)
24	6-May-03		2013	2013		24531	24531	Last detected 30 August 2003 2:34:46 PM in VRAP array
25	22-Apr-03		634	634		8615	8615	Last detected 9 October 2003 1:22:21 AM at VR2 7 (upstream)
26	29-Jul-03		1469	1469		6306	6306	Last detected 15 September 2003 4:44:12 PM at VR2 7 (upstream)
27	29-Jul-03		48	48		3130	3130	Last detected 15 August 2003 2:34:59 AM at VR2 7 (upstream)
28	29-Jul-03		63	63		937	937	Last detected 19 August 2003 9:33:55 PM at VR2 6 (upstream)
29	29-Jul-03		1377	1377		4197	4197	Last detected 12 September 2003 1:54:37 AM at VR2 7 (upstream)
30	29-Jul-03		991	991		1132	1132	Last detected 7 August 2003 11:34:58 AM at VR2 6 (upstream)
31	29-Jul-03		707	707		3406	3406	Last detected 14 August 2003 6:56:19 AM at VR2 3 (downstream)

Table 3. Number of times individual fish were detected by the positioning system and the data logging receivers, and last known detection date and location.

		Number of detections by acoustic receiver system by year						
Fish	Date	Positioning array			Data loggers			
ID	tagged	2002	2003	Total	2002	2003	Total	Fate
251	20-Aug-02	9142	188	9330	1065	23721	24786	Last detected 9 August 2003 9:37:30 PM at VR2 4 (downstream)
252	20-Aug-02	6674	1941	8615	653	672	1325	Last detected 14 September 2003 5:23:14 AM in VRAP array
253	20-Aug-02	13186	6	13192	402	606	1008	Last detected 3 October 2003 8:10:37 PM at VR2 7 (upstream)
254	6-May-03		2394	2394		3818	3818	Last detected 18 September 2003 7:45:14 PM at VR2 7 (upstream)
255	21-Aug-02	102	380	482	1333	969	2302	Last detected 29 May 2003 12:47:28 PM at VR2 3 (downstream)
256	22-Apr-03		36	36		1379	1379	Last detected 25 August 2003 2:42:29 AM at VR2 1 (downstream)
Totals		74204	88361	162565	37560	269502	307062	

Table 4. Summary of depth use of all sturgeon monitored at Three Tree Point in 2002 and 2003 and results from mixed model analyses.

Period	Mean Depth (m)	Standard Error	Standard Deviation	Model
1000 – 1400 hrs	17.3	0.02	7.3	
2200 – 0200 hrs	10.9	0.02	5.8	
				$P<0.0001$; F=633,214

Dispersion of tagged sturgeon differed in spatial extent among individuals with some fish occupying relatively small areas within the VRAP array and others moving between VRAP and VR2 arrays extensively. Dispersion was well represented in the individual fish histories in Appendix F. Some fish (e.g. ID 17) remained within the VRAP array for long periods of time between seasonal migrations while others (e.g. ID 18) moved between the VRAP array and VR2 receivers regularly. Thus dispersion of sturgeon is variable and is most likely dependent upon individual traits. It was not unexpected to find that some white sturgeon moved considerably within the 4-mile river reach monitored by the VRAP array and VR2 receivers. White sturgeon from the Columbia River have been recovered hundreds of miles from the initial capture location (Devore et al. 1995).

Diurnal and nocturnal depth use and spatial location of white sturgeon was a good indicator of localized movement at Three Tree Point. White sturgeon showed fidelity to different depths and, for some fish, fidelity to specific geographic areas among crepuscular periods. For some fish, localized movements shown by changes in depth occurred over very small geographic distances because the riverbed topography allowed fish to alter their depth with little horizontal movement.

3.3 Sturgeon behavior during dredging operations

The long-term deployment of the VRAP array and continuous monitoring of fish movements provided the ability to analyze white sturgeon response to dredging operations. The pipeline dredge Oregon performed maintenance dredging operations immediately adjacent to and within the VRAP array in the fall of 2002 and again in the summer of 2003. In May 2003, the hopper dredge Essayons was tasked specifically to perform disposal operations within the VRAP array for the purpose of monitoring sturgeon reaction. The pipeline dredge operations were relatively lengthy, entailing dredge and pipeline setup prior to cutting, 10 – 12 days of cutting and disposal, and then removal of the moorings for the pipeline and dredge. Pipeline dredge operations were halted during weekends and holidays. The hopper dredge disposal test was performed over a 24-hour period. Hopper dredge operations do not require mobilization and demobilization over work sites. Thus, the hopper disposal test was considered to be a test of an acute disturbance as opposed to the chronic disturbance of pipeline dredging operations.

Tagged white sturgeon were present in the area prior to each dredging operation and fish locations were monitored by the VRAP array during all three dredging operations (Table 5). Some individuals were monitored during all three dredging operations.

Table 5. Identification codes of white sturgeon present during dredging operations that occurred during this study. Fish ID codes can be cross-referenced to other tables in this report for more information. An "X" indicates that the fish was present immediately before dredging operations began. Absence of a date in the arrival or departure columns indicates that the fish was monitored throughout the dredging operation. Arrival and departure dates indicate arrival after dredging operations began or departure before operations ceased.

	Pipeline Dredge						Hopper Dredge		
	19 Sept - 02 Oct 2002			25 June - 10 July 2003			20 - 21 May 2003		
ID	Present	Date arrived	Date departed	Present	Date arrived	Date departed	Present	Date arrived	Date departed
5	X			X			X		
6		19 Sept							
7				X					
9				X					
11	X						X		
14	X								
15	X		19 Sept						
16	X		19 Sept						
17	X		26 Sept	X			X		
18					25 June				
19	X		27 Sept						
21								21 May	21 May
23							X		21 May
24							X		
251	X								
252	X			X			X		
253	X								
254				X			X		

3.3.1 Pipeline Dredge Operations

3.3.1.1 Fall 2002

The Oregon started working near the VRAP array on 19 September 2002. Setup began at 0800 hrs and dredging began at 1400 hrs. On that day, 10 white sturgeon were being monitored within the VRAP array. Underwater noise generated by the pipeline dredging operations did not seem to affect reception of tags by the positioning system. Two sturgeon departed and one fish entered the VRAP array during the setup period. One fish departed at 1040 hrs (ID 15) and another at 1206 hrs (ID 16). One sturgeon entered the array at 1033 hrs (ID 6). Nine fish were still present 24 hours after the dredging operation began. During the two-week operation two more fish departed (ID 17 on 26 September and ID 19 on 27 September) and no other fish arrived (Table 4).

Movement and depth use by fish before and during dredging differed across periods indicating some reaction to dredging operations. Sturgeon were more active during dredging (mean movement = 52.6 m, SE = 0.80) than before dredging occurred (mean movement = 42.5 m, SE = 0.61) ($F_{2, 17000}$=4,950.6, P<0.0001; Table 6). Sturgeon were located in deeper water before dredging began (mean depth = 17.7 m, SE = 0.08) than during dredging (mean depth = 16.2 m, SE = 0.09) ($F_{2, 10000}$ = 39,807.3, P<0.0001; Table 6).

Table 6. Results from repeated-measures mixed model ANOVA for the two pipeline dredge operations that occurred near Three Tree Point.

Period	df	*F*	*P*
2002			
Movement (m)	17,000	4,590.6	<0.0001
Depth (m)	10,000	39,807.3	<0.0001
2003			
Movement (m)	4,552	1,672.9	<0.0001
Depth (m)	4,089	12,734.6	<0.0001

Kernel home range estimates showed a shift in sturgeon utilization distribution towards the dredging operation during the first 24 h and also during the entire two-week operation (Figure 7). While the entire kernel density plot shifted towards the dredging operation, the 95 % density of locations showed a shift away from the pipeline disposal area. Distance from the center of the 95 % utilization distribution to the edge of the disposal area was 712 m and 890 m for before and during-dredging periods, respectively.

Generally, individual tagged sturgeon occupied similar home ranges throughout the before and during-dredging periods. However, a few fish made distinct forays towards the dredge and to the disposal outlet pipe. These forays account for the shift in utilization distributions towards the pipeline dredging operation. Most of the fish that moved towards the dredging operation did not remain near the dredge for long periods of time. Perhaps these were investigative forays in response to a perceived disturbance. However, one fish (ID 6) did stay in close proximity to the dredge for most of the two-week operation. This fish is intriguing because it left the study area immediately after it was tagged on 14 August 2002 and returned to the positioning array during the second day of pipeline dredging operations.

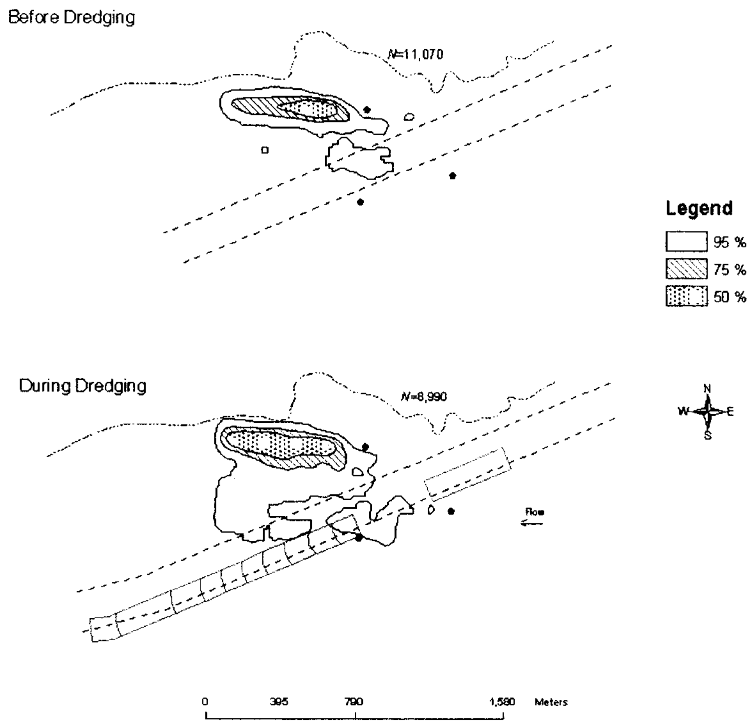

Figure 7. Kernel home ranges for all sturgeon monitored 2 weeks before and 2 weeks during the 2002 pipeline dredging operation. The upper dashed line represents the Washington shoreline and the lower parallel dashed lines depict the Federal Navigation Channel. The VRAP system buoys are shown as three black dots. The 95, 75, and 50 % utilization distributions for monitored fish are depicted. The locations of dredging operations are represented by shaded polygons; the longer polygon to the west depicts the cutting area and the polygon within the VRAP array depicts the area where disposal occurred.

3.3.1.2 Summer 2003

In 2003 the Oregon began working on 25 June immediately adjacent to the VRAP array. As during 2002, underwater noise caused by the activity did not appear to affect detection of tags. Seven white sturgeon were present when the dredging began. During the first day of operation, one tagged sturgeon entered the VRAP array at 0934 hrs (ID 18), and one tagged sturgeon departed at 2040 hrs (ID 7). Thus, 24 hrs after the operation began seven tagged sturgeon were still being monitored by the VRAP array. No other migrations of tagged sturgeon into or out of the VRAP array occurred throughout this operation, indicating no net emigration or immigration as a result of pipeline dredging operations. As in 2002, movement and depth use differed between before and during-dredging periods. Sturgeon were more active during dredging (mean movement = 58.2 m, SE = 1.60) than before dredging occurred (mean movement = 56.3 m, SE = 1.25) ($F_{2, 4,552}$=1,672.9, P<0.0001; Table 6). Sturgeon were located in deeper areas before dredging (mean movement = 15.7 m, SE = 0.12) than during the first week of dredging (mean movement = 13.6 m, SE = 0.15) ($F_{2, 4,089}$ = 12,734.6, P<0.0001; Table 6). While these findings were statistically significant, their biological significance is difficult to comprehend given the small (< 2 m) differences in both means. Differences in movement and depth during dredging could indicate increased foraging activity or a response to increased stress, or the differences could be a seasonal response unrelated to the dredging activity.

Kernel home range estimates for this dredging operation showed little difference in the utilization distribution of tagged sturgeon when comparing before and during-dredging periods (Figure 8). Most monitored sturgeon generally occupied the same home ranges

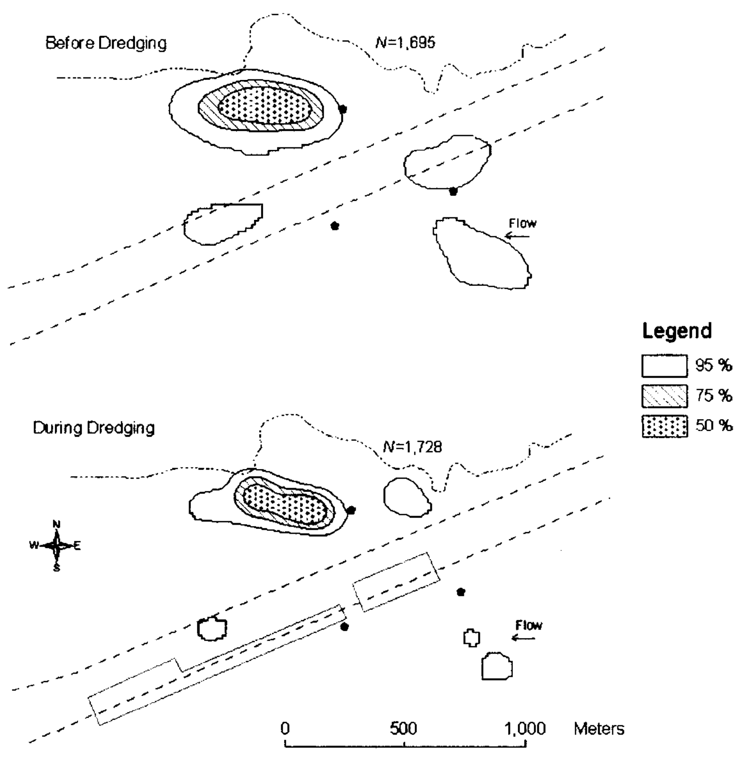

Figure 8. Kernel home ranges for all sturgeon monitored 1 week before and for the first week during the 2003 pipeline dredging operation. The upper dashed line represents the Washington shoreline and the lower parallel dashed lines depict the Federal Navigation Channel. The VRAP system buoys are shown as three black dots. The 95, 75, and 50 % utilization distributions for monitored fish are depicted. The locations of dredging operations are represented by shaded polygons; the longer polygon to the west depicts the cutting area and the polygon within the VRAP array depicts the area where disposal occurred.

throughout this pipeline dredging operation. During the first 24 h, two sturgeon made forays towards the dredging operation but did not stay near the dredge for enough time to shift the 95 % utilization distribution. Movements by these two fish likely resulted in the significant difference in activity noted above.

3.3.2 Hopper Dredge Disposal

In May 2003, the Essayons was tasked to make a series of disposals in the VRAP array during a 24 hr period. The Essayons made its first disposal at 1853 hrs on 20 May 2003 and made a 12th and last disposal at 1801 hrs on 21 May. The mean time for disposal (doors opened to doors closed) for these 12 distinct disposals was 7 min (range 5-11 min) and the time between individual disposal events was just under 2 hrs. All disposals began with the Essayons entering the VRAP array from downstream and opening the hopper doors while the vessel was inside the VRAP array. The vessel passed outside the triangle formed by the VRAP buoys before the hopper doors were closed but remained well within the detection radius of the VRAP array.

The short duration of the entire disposal test (24 hrs) enabled analyses to incorporate before, during, and after-disposal test comparisons. Although underwater noise generated from the ship precluded monitoring fish movements during the actual disposal operations, the twelve 5 to 11 min gaps in data were not detrimental to the analyses. Unfortunately, the VRAP system malfunctioned between 1500 hrs on 19 May and 0900 hours on 20 May, precluding a direct comparison of fish activity 24 hrs immediately prior to disposal operations. Therefore, we used the 24 h period from 1500 hrs on 18 May to 1500 hrs on 19 May for the before-dredging period in the 24 h comparisons.

Seven sturgeon were being monitored by the VRAP array when disposal operations began (Table 5). During the early morning on 21 May, another fish (ID 25) quickly passed through the VRAP array yielding only two geographic coordinate locations. This fish was not used in the analyses.

Analyses of movements and depths indicated a mixed reaction to disposal operations. The repeated-measures mixed model ANOVA indicated that sturgeon movements ($F_{3,\,1,806}$=321.7, P<0.0001) and depths ($F_{3,\,1,658}$=6,482.6, P<0.0001; Table 7) differed in the 24 h period comparisons. The least-squares means comparison confirmed that sturgeon moved more (lsmean movement = 60.0 m, SE = 2.9) after the 24 h disposal than during or before (before vs. after P<0.0001; during vs. after P=0.0074; Figure 9). However, the least-squares means comparison did not reveal any differences in depth use between periods. It is not uncommon to see an overall model difference but no differences between means tested. Therefore, results from the mean comparison revealing that there was no difference in depth use among the three periods compared are taken as the most valid.

Table 7. Results from repeated-measures mixed model ANOVA for the hopper dredge Essayons at Three Tree Point.

Period	Df	*F*	*P*
24 h blocks			
Movement (m)	1,806	321.7	<0.0001
Depth (m)	1,658	6,482.6	<0.0001
20 min blocks			
Movement (m)	312	147.7	<0.0001
Depth (m)	285	1,423.3	<0.0001

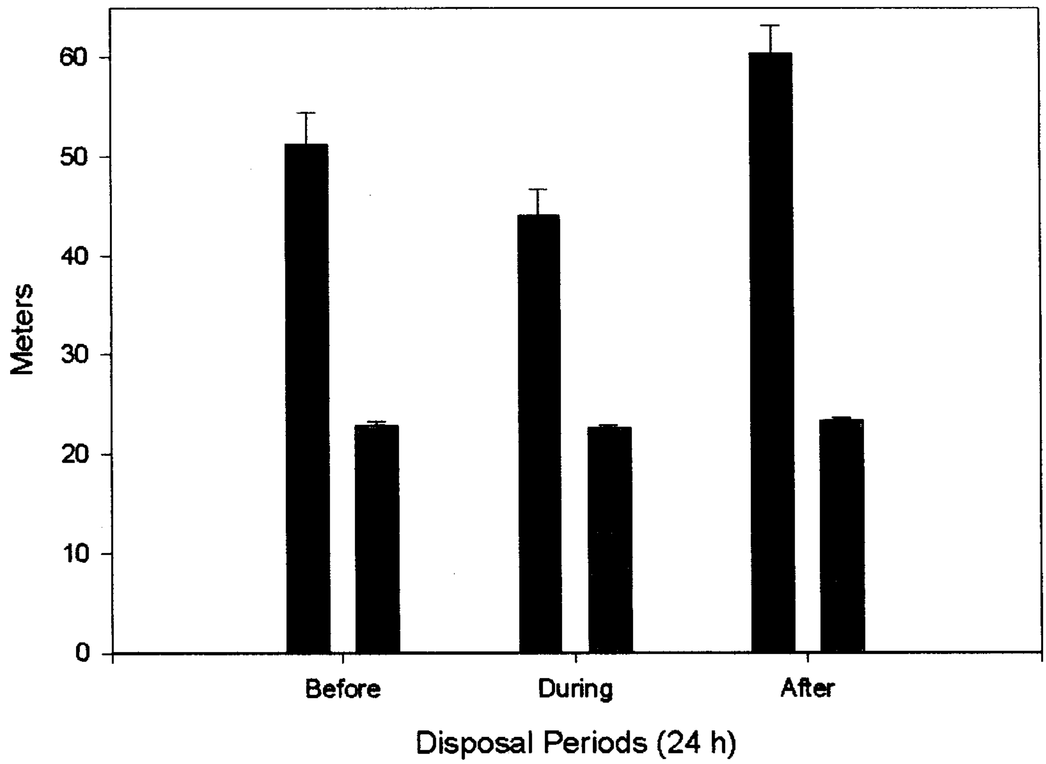

Figure 9. Mean movement (black bars) and mean depth (gray bars) comparisons among the 24 h periods. Standard errors are represented by the lines above each bar.

Kernel home ranges revealed a slight expansion in the utilization distribution during the 24 hours when disposal occurred (Figure 10). Some sturgeon made forays towards the disposal area and into the Federal navigation channel downstream from the disposal area while the disposals were ongoing. Home ranges receded slightly during the 24 hr period after the disposals occurred.

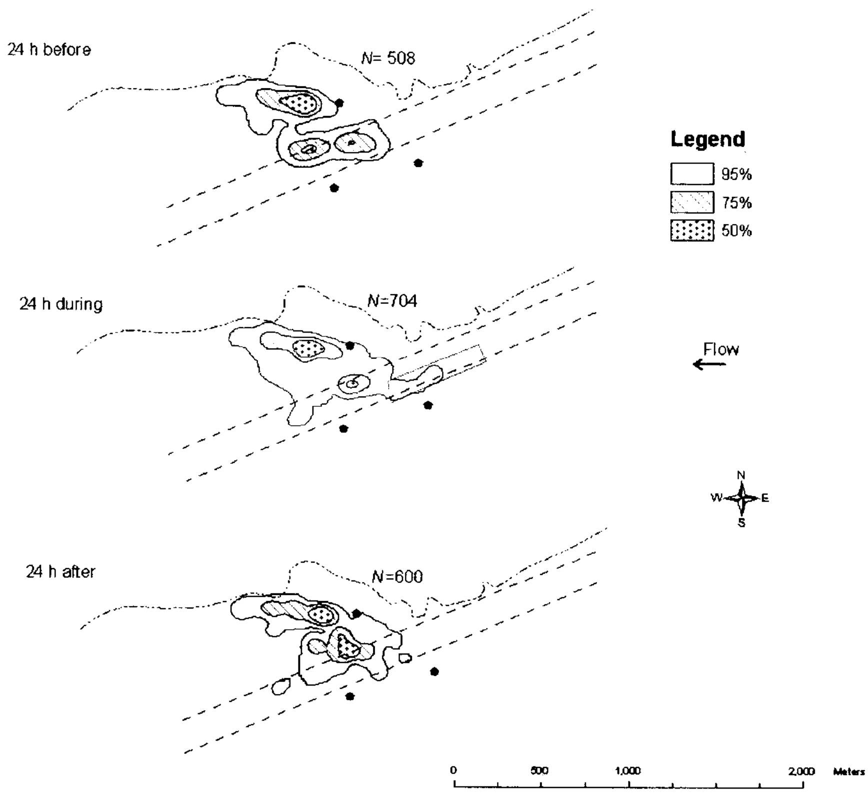

Figure 10. Kernel home ranges for all sturgeon monitored 24 hours before, 24 hours during, and 24 hours after the hopper dredge disposal operation. The upper dashed line represents the Washington shoreline and the lower parallel dashed lines depict the Federal Navigation Channel. The VRAP system buoys are shown as three black dots. The 95, 75, and 50 % utilization distributions for monitored fish are depicted. The location of disposal area is represented by the shaded polygon in the middle graphic.

One fish (ID 254; 64 cm TL) had a home range in the Federal navigation channel where disposals were going to occur. This fish maintained this home range throughout the 24 h disposal cycle (Figure 11). Other fish showed limited changes in home ranges in each of the three 24 h periods analyzed.

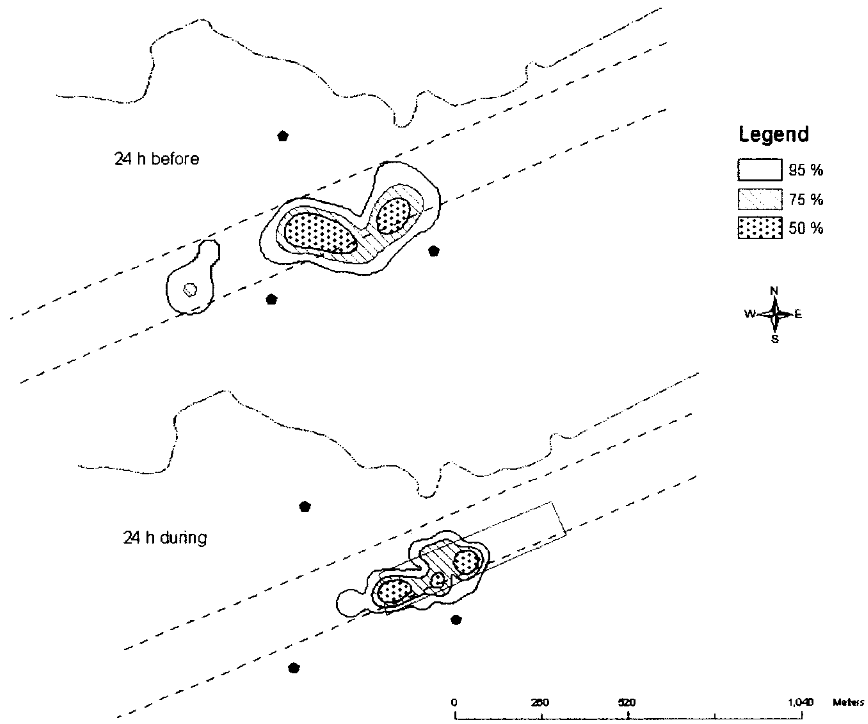

Figure 11. Kernel home ranges for one sturgeon (ID 254) monitored before and during the hopper dredge disposal operation. The upper dashed line represents the Washington shoreline and the lower parallel dashed lines depict the Federal Navigation Channel. The VRAP system buoys are shown as three black dots. The 95, 75, and 50 % utilization distributions for monitored fish are depicted. The location of disposal area is represented by the shaded polygon in the lower graphic.

The discrete nature of each of the 12 disposals that occurred enabled an analysis of sturgeon behavior immediately before and immediately after each event. Sturgeon movement differed ($F_{2, 312}$ = 147.7, P<0.0001; Table 7) among the 20 min before and 20 min after-disposal time blocks. Sturgeon moved more immediately after (mean movement = 51.5 m, SE = 4.4) than just before (mean movement = 41.0 m; SE = 3.0) each disposal. Sturgeon depths also differed ($F_{2, 285}$ = 1,423.3, P<0.0001) immediately before and after each individual disposal event. Sturgeon were located deeper (mean movement = 23.0 m, SE = 0.6) during the 20 min after each disposal than just before each event (mean movement = 22.3 m, SE = 0.6). The Mann-Whitney test did not indicate any differences in distance from fish locations to the disposal area when 20 min before and 20 min after-disposal periods were compared ($U_{(2), 164,172}$ = 27,123).

Kernels built from the 20 min before and 20 min after-disposal periods revealed an expansion of the kernel and a shift in the 50 % utilization towards the disposal area in the 20 min after period (Figure 12). Combined, these results indicate that fish became more active as a result of each individual disposal event and that this increased activity was not a result of movement away from the disposal site. The kernels indicate that fish were located closer to the disposal site immediately after each disposal event.

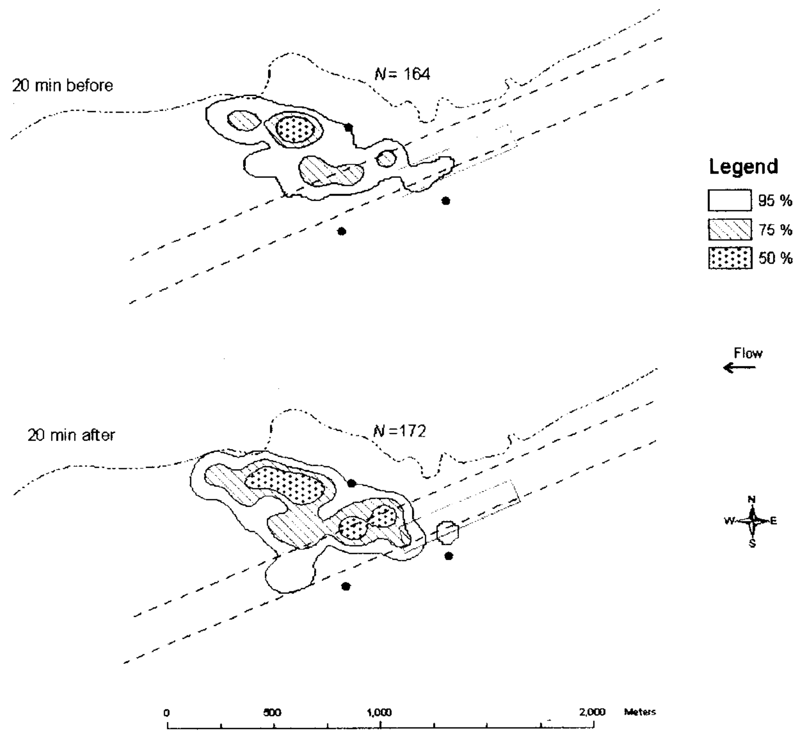

Figure 12. Kernel home ranges for all sturgeon monitored 20 min before and 20 min after all 12 disposals during the hopper dredge disposal test. The upper dashed line represents the Washington shoreline and the lower parallel dashed lines depict the Federal Navigation Channel. The VRAP system buoys are shown as three black dots. The 95, 75, and 50 % utilization distributions for monitored fish are depicted. The location of the disposal area is represented by the shaded polygon in the graphics.

3.4 Habitat associations

Calculating the density of fish locations per unit area for intervals of different habitat descriptors identified habitats associated with fish locations obtained with the VRAP array. While the data are biased because they represent fish use within a very localized area, the information is useful to better understand how white sturgeon use habitats associated with deeper reaches of the lower Columbia River. These deep "holes" are relatively rare in the lower Columbia and are separated by variable-length runs of shallower riverine habitat.

3.4.1 Depth

White sturgeon used a variety of river depths (Figure 13). However, individual locations were more frequently associated with water depths between 11 and 110 ft (3.4 and 33.5 m), with 80% of the locations associated with depths between 51 and 110 ft (15.5 and 33.5 m). Density of locations per depth interval reveal a slightly bimodal distribution of depth use, with peak densities occurring at depths between 31 to 60 ft (9.4 to 18.3 m) and 91 to 120 ft (27.7 to 36.6 m). This bimodal distribution in depth use may result from a propensity to move to shallower water at night.

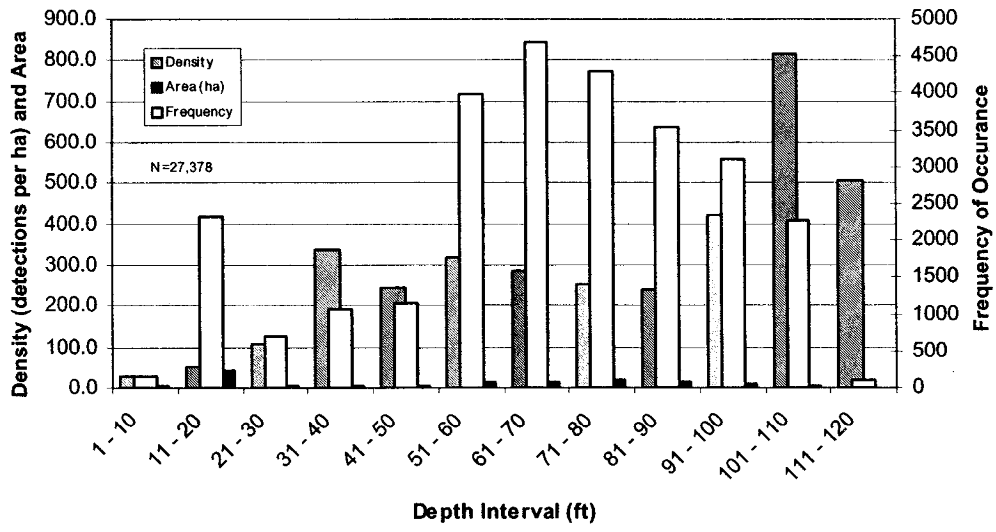

Figure 13. Density and frequency of occurrence of fish locations over depth intervals. Area occupied by each depth interval is also indicated on the left axis.

3.4.2 Riverbed Slope

White sturgeon were found more frequently over areas with low to moderate riverbed slopes (0 – 20 degrees; Figure 14), but densities were greater at moderate to high slopes (21 – 45 degrees). This indicates a probable preference for the sloping areas that can occur on the sides of the river channel or on in-channel sloping areas formed by hydrologic features.

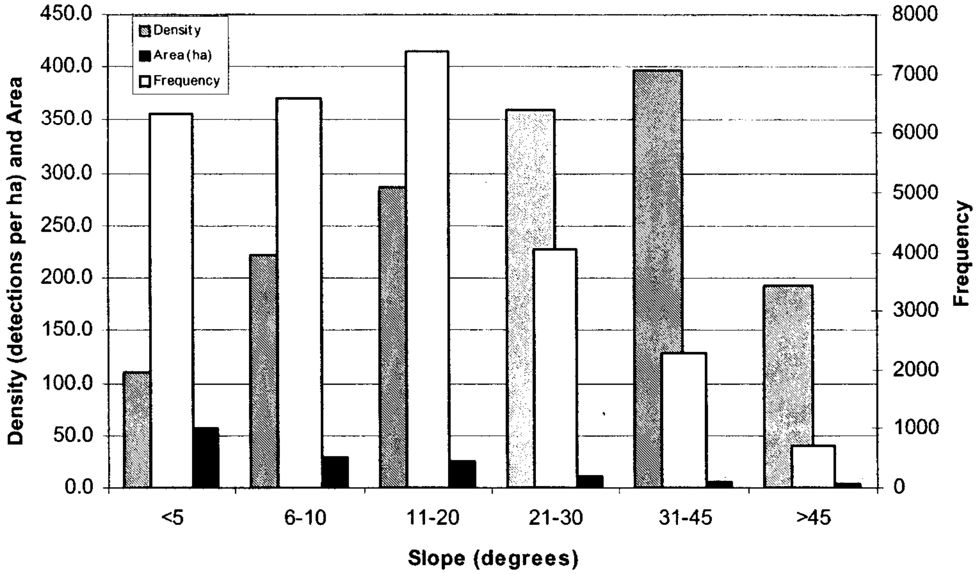

Figure 14. Density (hatched bars) and frequency of occurrence (light bars) of fish locations over riverbed slope categories. The area (dark bars) occupied by each slope interval is also indicated on the left axis.

3.4.3 Riverbed Roughness

Many fish species orient to physical riverbed structure such as sand dunes or rock outcrops. The standard deviation of riverbed slopes over a 30 m radius provided a means of categorizing riverbed areas by degree of topographical relief. Although white sturgeon were more frequently associated with areas with low topographical relief (Figure 15), this type of habitat was more prevalent and densities were greater over areas with moderate topographical relief. Sturgeon density was lowest in areas with more extreme topography.

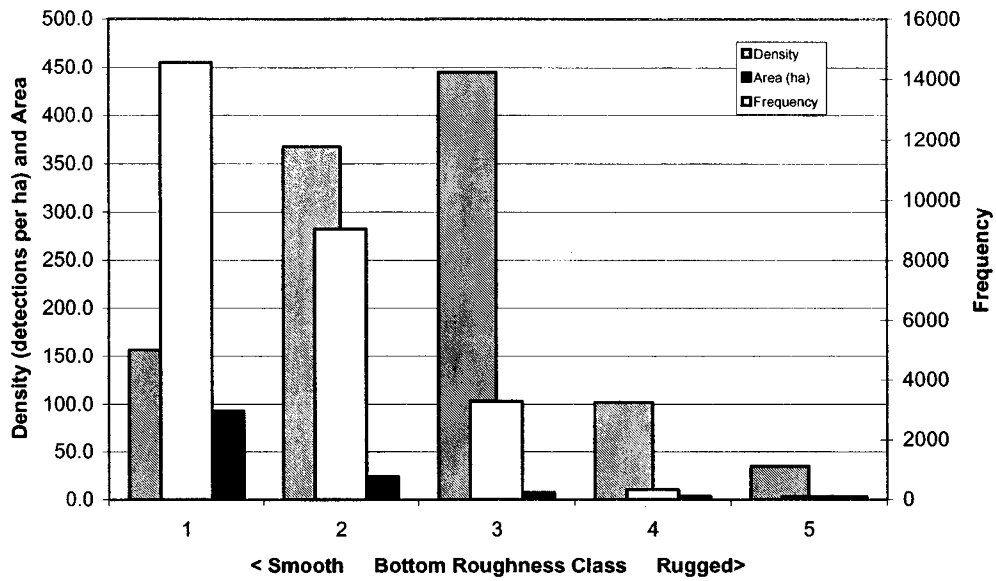

Figure 15. Density (hatched bars) and frequency of occurrence (light bars) of fish locations over riverbed bottom roughness categories. Bottom roughness was determined by calculating the standard deviation of the riverbed slope over a 30 m radius. The area (dark bars) occupied by each bottom roughness class interval is also indicated on the left axis.

4.0 Conclusions

The continuous monitoring of white sturgeon activity within the study area provided information that managers can use to assess the potential for anthropogenic effects on white sturgeon and their habitat. The approach of a long-term deployment of two types of acoustic telemetry systems – individual data loggers and a separate positioning system – met spatial and temporal data requirements for the multiple objectives of this study. While the geographic extent of the study area was limited and did not encompass the entire home range of the fish monitored, the data are useful for describing how white sturgeon behaved over time, habitats that were occupied in this area, and how they reacted around pipeline and hopper dredge operations. Much of this information is likely transferable to other freshwater areas in the lower Columbia River. That is, the findings from this study should be useable by managers to address issues raised regarding human influences on white sturgeon individuals or habitat. One caveat that must be considered is that the positioning system itself was located over a deep depression that exceeded 30 m in depth. This type of habitat is relatively rare in the lower Columbia River. While this study resulted in unprecedented information on how white sturgeon use this type of habitat, it is not known if sturgeon behave similarly in or show fidelity to the shallower run-type habitats that exist between the deeper depressions in the riverbed.

Pipeline dredging operations and hopper dredge disposal operations did not result in white sturgeon emigration from the local area where the operations occurred. Fish showed increased movements during dredging operations with small shifts in geographic location, generally toward the source of disturbance. It is likely that the increased movements were a result of increased foraging activity. However, it was beyond the scope of this study to determine if fish were actually feeding during these operations and whether they benefited or not from the increased activity. Some recreational fishermen refer to a "dredge bite" implying a greater potential to catch sturgeon near dredging operations. This supports a hypothesis that sturgeon increase foraging activity near dredging operations.

Seasonal migration of white sturgeon was confirmed during this study. The geographic extent of the study area did not encompass the entire home range of the tagged individuals. This precluded the identification of the maximum extent of migrations made by individuals. However, continuous monitoring with the acoustic receivers revealed that white sturgeon captured within the study area during August were not present between river miles 28 and 32 during December through mid April. Attempts to capture sturgeon with setlines near river mile 30 during January through March also failed, providing additional evidence of a seasonal migration. The majority of tagged sturgeon that returned to the study area in April did so from upriver, indicating that wintering grounds for white sturgeon are located upstream from river mile 32. Many of the sturgeon captured and tagged during April 2003 proceeded downriver shortly after they were captured, suggesting that a migration between wintering and summering grounds was underway during spring. The return in April 2003 of 15 of 17 fish that departed the area during the fall of 2002 indicates a very high degree of fidelity to this river reach.

White sturgeon typically moved to shallower water at night. The mean nighttime depth was 36 ft (10.9 m) compared to a mean daytime depth of 57 ft (17.3 m). For some fish, rapidly changing riverbed morphology enabled them to make large changes in depth with little shift in horizontal location. Other fish made relatively lengthy daily movements to alter their depths. It was beyond the scope of this study to determine why these daily movements occurred. The fish appeared to move continuously during day and night, with no lengthy periods of rest or torpor common in many benthic-oriented fish species. If foraging is a continuous activity, it is possible that the fish are either following a migratory prey or they are exploiting a prey that is more prevalent in shallow water at night. It is also quite likely that the fish are photophobic to some extent and prefer deeper, darker water during daytime.

White sturgeon used a variety of habitats, and, as described above, use varied diurnally. The range within each habitat descriptor was quite broad, and at the population level, white sturgeon at one time or another occupied nearly every habitat type available. This poses interesting challenges for managers seeking to minimize human impacts to white sturgeon, white sturgeon habitat, or to mitigate for habitat alterations. The spatial and temporal extent and nature of the disturbance should be taken into consideration. As an example, a daytime disturbance that occurs in shallow water may have minimal short-term effects on individual white sturgeon because they would likely be located nearby in deeper water. Evaluations of longer-term physical disturbance to geographic areas would need to consider the wide variability in habitats used by white sturgeon, the seasonal occupancy resulting from migrations, and the dynamic nature of the tidally-influenced lower Columbia River. This study did not address questions about how sturgeon forage and where benthic prey items found in the diet of white sturgeon actually originated. White sturgeon captured at Three Tree Point during the study by the Oregon Department of Fish and Wildlife (Romano et al. 2002) had fed on benthic invertebrates, yet because of the dynamic nature of the sandy river bedforms in this area, the local production of benthic invertebrates is probably quite limited. This, coupled with the limited movements of some fish observed in this study, would suggest that white sturgeon at Three Tree Point may be feeding on prey items that originated from other areas and were transported by river currents.

Studies of riverine fish have largely focused on the importance and stability of habitat quality and have largely ignored the role of fish behavior – particularly site fidelity. The propensity to exhibit site fidelity has potentially large implications because fish with high fidelity to a site may not use high-quality habitat patches located outside the area to which fidelity is exhibited (Railsback et al. 1999). This behavior may place limitations on the response of fish to changes in habitat quality (Crook 2004). This could confound attempts to evaluate habitat perturbations on sturgeon populations based on habitat only because it should be expected that some high quality habitats may not always be occupied by white sturgeon and that disturbance to habitat that results in a reduction of habitat quality may not immediately result in fish dispersal. It is not yet known how these behavioral traits influence population productivity.

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APPENDIX A. Speed of sound in water measurements obtained from August 2002 through September 2003 near Three Tree Point.

Date	Temperature (°C)	Measured speed of sound in water (m/sec)
1-Aug-2002	20.8	1485
15-Aug-2002	21.2	1486
26-Sep-2002	18.5	1478
16-Oct-2002	15.3	1468
7-Nov-2002	10.1	1448
26-Nov-2002	10.0	1448
31-Dec-2002	6.9	1435
4-Feb-2003	7.2	1437
12-Feb-2003	6.1	1432
29-Apr-2003	11.3	1454
6-May-2003	11.6	1454
22-May-2003	13.5	1461
2-Jun-2003	15.0	1467
6-Jun-2003	16.3	1471
25-Jun-2003	16.7	1473
1-Aug-2003	21.9	1489
12-Aug-2003	22.1	1490
28-Aug-2003	21.3	1487
10-Sep-2003	20.8	1486
30-Sep-2003	18.9	1480

APPENDIX B. Accuracy Assessment of the Radio Acoustic Positioning System Deployed at Three Tree Point

The VEMCO Radio-linked Acoustic Positioning (VRAP) System is expected to achieve accuracies of 2-5 m within the triangle formed by the three buoys and to have decreasing accuracy with increasing distance outside of the triangle. Klimley et al. (2001) provides a thorough description of theory and operation of the VRAP system. Factors important to the accuracy of the VRAP system include environmental acoustic conditions and buoy movement. The VRAP system deployed at Three Tree Point was in a highly variable environment with constantly changing acoustic conditions and movement of buoys due to tidal flux and river discharge. Sources contributing to acoustic error include multi-path signals, ambient noise causing false detections, and collisions among acoustic transmissions that overlap in time. System clock error can also contribute to decreased accuracy. Accuracy is also known to decrease with increasing transmitter distance from the VRAP buoy array.

Methods

Accuracy of the VRAP system was tested using free-floating drogues that housed a coded transmitter and a Global Positioning System (GPS) receiver. The VRAP array logged transmitter positions while the GPS receiver logged the drogue path. GPS tracks were considered the true path for each drogue drift. The clock at the base station of the VRAP array was operating using GPS time, allowing a temporal comparison of drogue position between systems.

Drogues (Figure 1) were constructed at the USGS's Columbia River Research Laboratory and consisted of an aluminum foil to catch the current and add stability, a PVC pipe to which a transmitter was attached, a large PVC float (1 x 0.25 m) that housed the GPS receiver, and a cable to connect the foil to the float. Acoustic transmitters equipped with pressure sensors (V16-4HP) were attached to the PVC pipe approximately 4 m below the water surface. The GPS receiver was housed inside a waterproof case placed on top of the PVC float with the GPS antenna on a threaded pipe directly above the transmitter. Drogues were released from a boat and drifted through and around the VRAP array multiple times to obtain simultaneous VRAP and GPS tracks.

A Trimble real-time kinematic (RTK) GPS was used to provide highly accurate locations of the drogue. The RTK GPS consisted of a base station located over a known surveyed position and one GPS receiver mounted on the drogue. The base station compared its calculated position to the known true surveyed position and used a radio modem to communicate that difference as a correction factor to the GPS receiver on the drogue, which then adjusted its calculated position. The RTK GPS base station was located on Fitzpatrick Island, OR, less than one mile (2.2 km) from the VRAP array. The RTK GPS track was considered accurate to +/-1 cm. Variable wave activity sometimes caused the drogue to tilt slightly adding additional error. However, because the VRAP array was expected to have 2-5 m positional error based on the manufacturer's specifications, error associated with misalignment of the drogues GPS antenna and the acoustic transmitter was considered negligible for this analysis.

Drogue work was conducted during three time periods during 2003; 25-27 February, 15-16 July, and 13-14 August. Geographic coordinates of the drogue obtained with the GPS and VRAP system were plotted in ArcView 3.3 and the measuring tool was used to determine distance between paired GPS and VRAP system points. Using the GPS coordinates as the true track, temporally paired location data was sorted by 100 m increments from the center of the VRAP array. Descriptive statistics such as mean difference in distance between GPS and VRAP positions, standard deviation of the mean, and coefficient of variation (CV) were calculated in quantify VRAP error.

Results

A total of 52 drogue drifts were completed which allowed a paired comparison of 354 positions (Figure 2). Few drifts were completed on the south (Oregon) side of the VRAP array because shallow water made it difficult to drift drogues through. Paired VRAP and GPS points summarized by 100 m increments from the center of the VRAP array (Table 1, Figure 3) had very high CVs indicating a high variation in differences between GPS and VRAP positions. High CVs mean high dispersion. As range from the center of the VRAP increased, CVs decreased, meaning the error was more similar within those ranges than compared to ranges closer to the center of the VRAP array. The biggest change in mean difference occurred at a distance between 900 and 1,000 m from the center of the VRAP array.

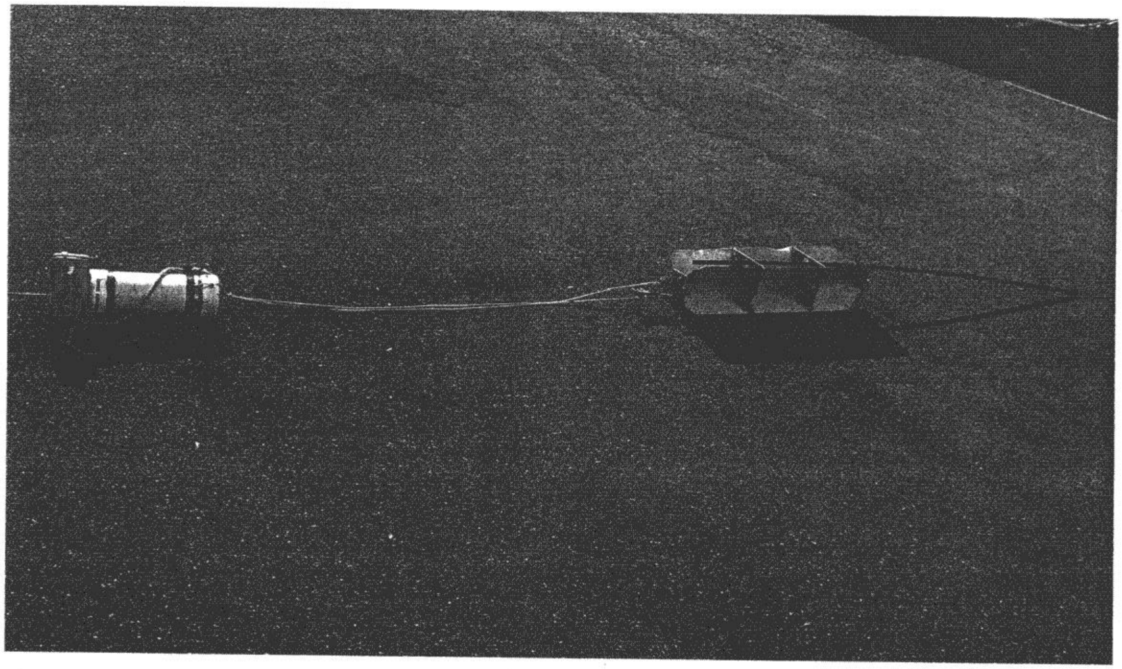
Table 1. Results from drogue tests in 100 m increments. Mean difference between VRAP and GPS points, standard deviation of the mean, and coefficient of variation are shown.

Range from VRAP (m)	N	Mean Difference	Standard Deviation	CV
100	42	9.9	13.1	132.2
200	19	8.9	11.8	132.7
300	54	12.7	26.4	209.0
400	40	17.9	31.3	174.8
500	24	10.6	10.4	98.6
600	44	21.9	25.9	118.4
700	19	30.3	28.9	95.4
800	41	29.4	21.9	74.4
900	24	32.2	31.1	96.5
1,000	16	58.2	44.9	77.1
1,100	31	54.4	52.1	95.8

Discussion

Results of this test were consistent with VRAP system specifications and manuals (Vemco Ltd. 2003). Most drifts were completed within and near the Federal Navigation Channel.

Figure 2 indicates a potential bias in sampling; however, most of the fish positions were also within and parallel to the navigation channel. We did not attempt to quantify shadow zone error. Too few drogue drifts were completed to derive error isopleths; however, the 100 m concentric summaries provided information useful for analyses of fish positions obtained with the VRAP array. Based on mean difference, SDs, and CVs it was deemed that fish positions within a 900 m radius of the center of the VRAP array were suitable for all analyses requiring relatively accurate fish positions.



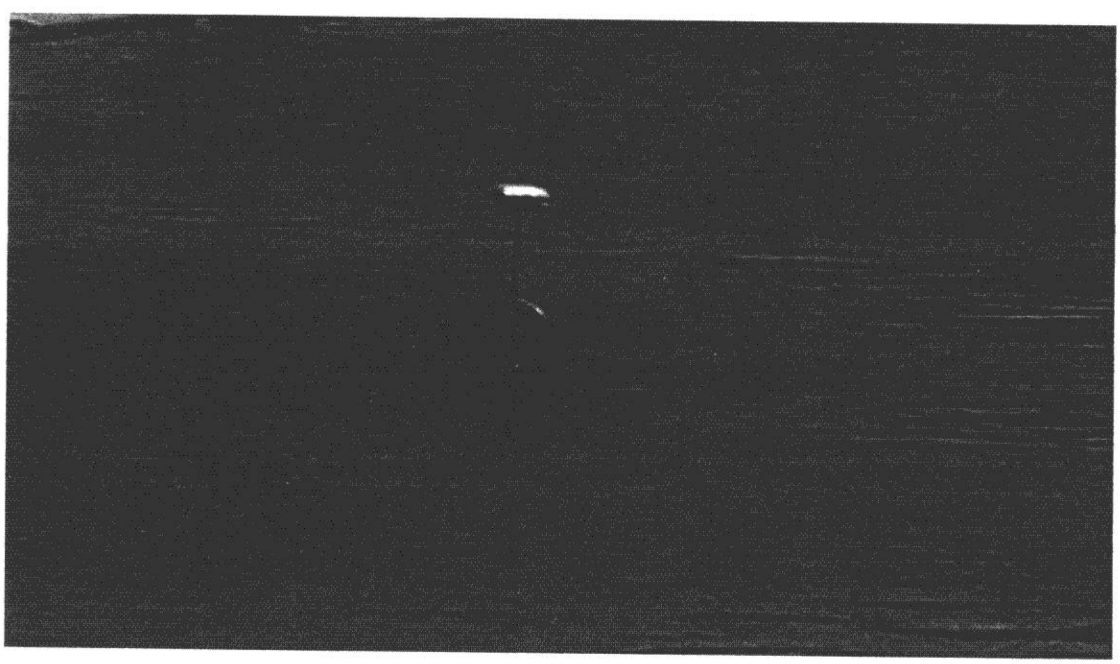


Figure 1. The upper graphic shows the construction details of the drogue used in this study. The bottom graphic shows the drogue floating in water with the GPS antenna on top of the black box housing the GPS receiver.

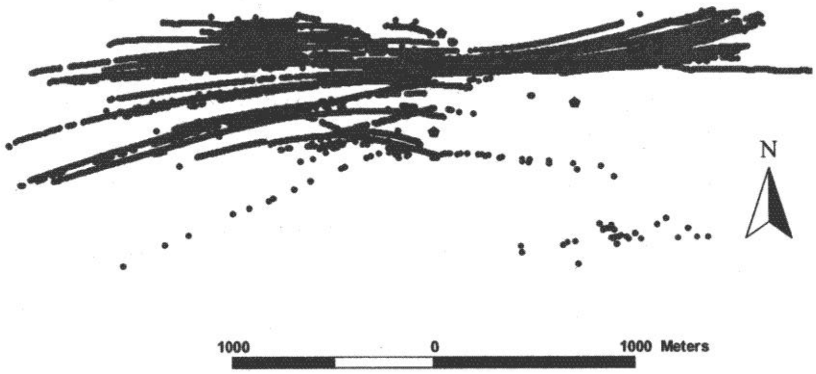


Figure 2. Results obtained from 52 individual drogue drifts. Light colored dots represent GPS positions and dark dots represent VRAP positions.

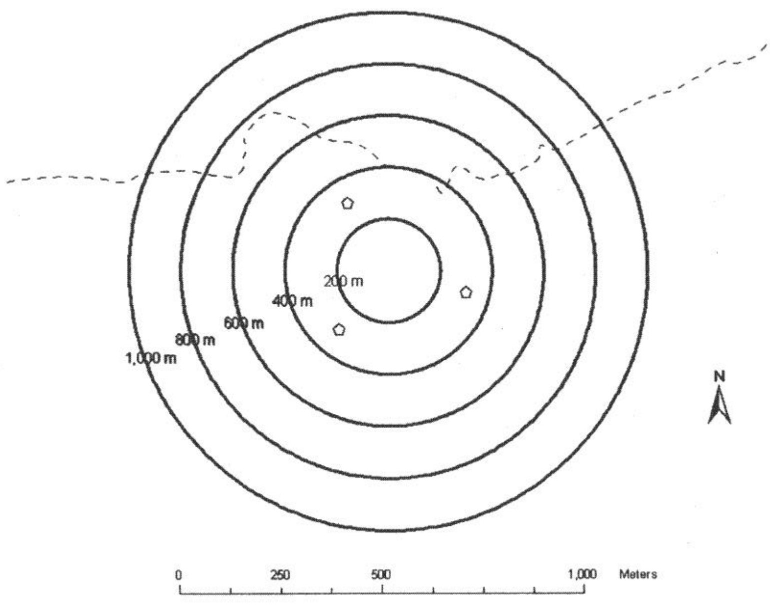


Figure 3. Illustration of the concentric interval method used to classify measured error of the VRAP system. The dashed line represents the Washington shoreline.

APPENDIX C. Pressure transmitter verification results.

Transmitters were lowered on a weighted line to known depths and the transmitted results were recorded either with a VR2 data-logging receiver or with the VRAP system. This was a verification only, not a calibration sequence. Most of the reported depths were within a meter of the known depths and within the manufacture's specifications.

		Depth reported by transmitter at known transmitter depths				
Tag ID	Date tested	2 m	5 m	10 m	20 m	25 m
5	8/8/02	2.0		9.9	19.2	
		2.0		9.9	19.2	
		2.2		9.7	19.3	
					19.3	
6	8/8/02	2.3		9.8	19.3	
		2.3		9.8		
		2.3		9.8		
		1.7		9.8		
7	8/8/02	1.9		9.6	19.0	
		2.1		9.4	19.0	
		1.9		9.6	19.0	
		1.9		9.6		
				9.6		
				9.6		
8	8/8/02	2.2		7.9	18.9	
		2.2		9.9	19.1	
		2.2		9.7	19.1	
				9.9	18.9	
				9.7		
				9.7		
9	8/8/02	1.8		9.2	18.7	
		1.8		9.2	18.5	
		1.8		9.4		
		1.6		9.2		
		1.4		9.2		
				9.4		
10	8/8/02	3.4		10.9	20.4	
		3.4		10.9	20.4	
		3.4		11.1	20.4	
		3.6		11.1		
		3.4		11.1		

Tag ID	Date tested	Depth reported by transmitter at known transmitter depths				
		2 m	5 m	10 m	20 m	25 m
				10.3		
11	8/13/02		5.127	10.3	19.7	
			4.922	10.3	19.7	
			4.922	10.0	19.7	
12	8/13/02		4.566	9.8	19.4	
			4.729	9.8	19.4	
			4.729	9.8	19.4	
13	8/13/02			9.9	19.4	
					19.4	
					19.4	
14	8/13/02		4.128	9.3	19.0	
			4.128	9.3	19.0	
			4.128	9.3	19.0	
15	8/13/02		4.966	10.3	19.9	
			4.966	10.3	19.9	
			4.966		19.9	
16	8/13/02		4.541		19.0	
			4.541			
			4.037			
16	8/14/02			9.6	19.2	
				9.6	19.2	
				9.6	19.2	
17	8/13/02		4.530	10.1	17.6	
			4.530	10.1	17.6	
			4.530	10.1	17.6	
17	8/14/02			9.6	19.3	
				9.6	19.3	
				9.6	19.1	
18	8/13/02		4.246	9.6	18.1	
			4.069		18.1	
			4.600		18.1	
18	8/14/02			9.7	19.3	
				9.7	19.3	
				9.4		

		Depth reported by transmitter at known transmitter depths				
Tag ID	Date tested	2 m	5 m	10 m	20 m	25 m
19	8/13/02		4.7	9.5	18.7	
			4.2	10.6	18.7	
			4.7	10.6	18.7	
19	8/14/02			9.7	19.4	
				9.7	19.4	
				9.7	19.2	
20	5/12/02			10.7	20.6	25.0
				10.7	20.6	
					20.4	
21	5/12/02			10.3	19.5	24.1
				10.0	19.5	
				10.2		
22	5/12/02			10.3	19.9	24.8
				10.3	19.9	24.6
				10.3	19.9	
23	5/12/02			10.3	20.1	24.9
				10.4	20.0	24.7
				10.3	20.0	
24	5/12/02			10.5	20.1	24.8
				10.5	20.1	24.7
					19.9	24.8
25	4/21/03		5.6	10.4		
			5.4	10.4		
			5.6	10.4		
				10.4		
26	4/21/03		5.9	10.6		
			5.9	10.4		
			6.1	10.4		
				10.8		
27	4/21/03		6.3	10.0		
			6.2	11.2		
			6.2	10.9		
			6.2			
28	4/21/03		5.6	10.2		

Tag ID	Date tested	Depth reported by transmitter at known transmitter depths				
		2 m	5 m	10 m	20 m	25 m
			5.4	10.2		
			5.2	10.2		
			5.2	10.2		
29	4/21/03		5.3	10.4		
			5.5	10.4		
			5.5	10.2		
			5.3	10.2		
30	4/21/03		5.7	10.5		
			5.6	10.4		
			5.7	10.5		
			5.6			
31	4/21/03		5.6	10.5		
			5.8	10.5		
			5.8	10.5		
			5.8			
			5.8			
32	4/21/03		5.4	10.2		
			5.8	10.3		
			5.8	10.2		
			5.8	10.2		
			5.8			
33	4/21/03		5.6	10.3		
			5.6	10.5		
			5.6	10.3		
			5.6	10.5		
34	4/21/03		5.5	10.4		
			5.5	10.4		
			5.7	10.4		
			5.7	10.4		

APPENDIX D. Commercial fishing periods that occurred during this study.

Season Opened	Season Closed	Species Allowed	Special Regulations Pertaining to Sturgeon
9/16/2002 7:00	9/16/2002 19:00	Salmon, Sturgeon	
9/19/2002 7:00	9/19/2002 19:00	Salmon, Sturgeon	
9/25/2002 7:00	9/25/2002 19:00	Salmon, Sturgeon	
9/24/2002 19:00	9/26/2002 7:00	Salmon, Sturgeon	Maximum 5 sturgeon may be possessed or sold during open period
9/30/2002 19:00	10/1/2002 19:00	Salmon, Sturgeon	Maximum 5 sturgeon may be possessed or sold during open period
10/2/2002 19:00	10/3/2002 19:00	Salmon, Sturgeon	Maximum 5 sturgeon may be possessed or sold during open period
10/6/2002 19:00	10/7/2002 19:00	Salmon, Sturgeon	Maximum 5 sturgeon may be possessed or sold during open period
10/9/2002 19:00	10/10/2002 19:00	Salmon, Sturgeon	Maximum 5 sturgeon may be possessed or sold during open period
10/14/2002 19:00	10/18/2002 7:00	Salmon, Sturgeon	Maximum 5 sturgeon per 24 hour period and maximum 15 per week
10/21/2002 19:00	10/25/2002 7:00	Salmon, Sturgeon	Maximum 5 sturgeon per 24 hour period and maximum 15 per week
10/28/2002 7:00	10/31/2002 7:00	Salmon Only	
1/7/2003 12:00	1/8/2003 18:00	Salmon, Sturgeon	
1/14/2003 12:00	1/15/2003 18:00	Salmon, Sturgeon	
1/21/2003 12:00	1/22/2003 18:00	Salmon, Sturgeon	
1/28/2003 6:00	1/28/2003 18:00	Salmon, Sturgeon	
2/17/2003 5:00	2/17/2003 21:00	Salmon, Sturgeon	Maximum 3 sturgeon may be possessed or sold during open period
2/19/2003 5:00	2/19/2003 21:00	Salmon, Sturgeon	Maximum 3 sturgeon may be possessed or sold during open period
3/21/2003 9:00	3/21/2003 19:00	Salmon, Sturgeon	
8/4/2003 19:00	8/5/2003 7:00	Salmon, Sturgeon	Maximum 7 sturgeon may be possessed or sold per week
8/6/2003 19:00	8/7/2003 7:00	Salmon, Sturgeon	Maximum 7 sturgeon may be possessed or sold per week
8/11/2003 19:00	8/12/2003 7:00	Salmon, Sturgeon	Maximum 7 sturgeon may be possessed or sold per week
8/13/2003 19:00	8/14/2003 7:00	Salmon, Sturgeon	Maximum 7 sturgeon may be possessed or sold per week
9/17/2003 19:00	9/19/2003 19:00	Salmon, Sturgeon	Maximum 3 sturgeon may be possessed or sold per week
9/21/2003 18:00	9/22/2003 18:00	Salmon, Sturgeon	Maximum 3 sturgeon may be possessed or sold per week
9/23/2003 18:00	9/25/2003 18:00	Salmon, Sturgeon	Maximum 3 sturgeon may be possessed or sold per week
9/28/2003 18:00	9/29/2003 18:00	Salmon, Sturgeon	Maximum 3 sturgeon may be possessed or sold per week
9/30/2003 18:00	10/2/2003 18:00	Salmon, Sturgeon	Maximum 3 sturgeon may be possessed or sold per week

Season Opened	Season Closed	Species Allowed	Special Regulations Pertaining to Sturgeon
10/5/2003 18:00	10/6/2003 18:00	Salmon, Sturgeon	Maximum 3 sturgeon may be possessed or sold per week
10/7/2003 18:00	10/7/2003 18:00	Salmon, Sturgeon	Maximum 3 sturgeon may be possessed or sold per week
10/12/2003 18:00	10/13/2003 18:00	Salmon, Sturgeon	Maximum 9 sturgeon may be possessed or sold per week
10/15/2003 6:00	10/17/2003 6:00	Salmon, Sturgeon	Maximum 9 sturgeon may be possessed or sold per week

APPENDIX E. Time periods when the VRAP system was not functioning.

Only periods greater than 3 hours are listed. The system was typically down for less than 3 hours during buoy replacements. Causes of the outages were generally attributed to radio communications failures between a buoy and the base station caused by external unknown factors. The outage between 21 November and 26 November 2002 was caused by an unknown source of radio interference and was resolved only by altering the frequency that was used for data communications.

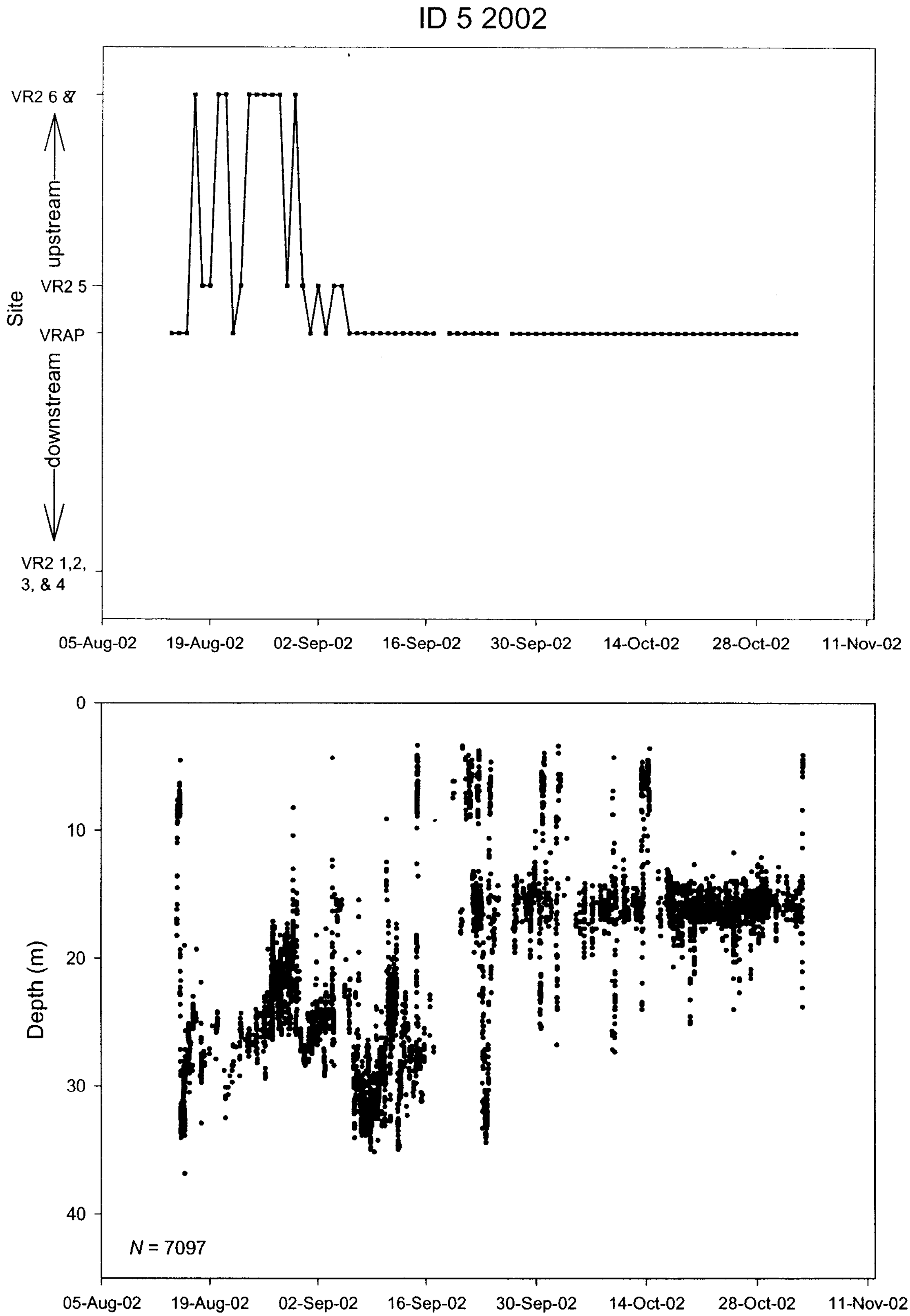
System down		System up		Down time (hrs)
Date	Time	Date	Time	
14-Aug-2002	7:07:07 AM	14-Aug-2002	2:33:56 PM	7.45
3-Sep-2002	11:12:13 AM	4-Sep-2002	11:46:52 AM	24.58
4-Sep-2002	3:01:01 PM	5-Sep-2002	7:06:35 AM	16.09
5-Sep-2002	7:10:16 AM	6-Sep-2002	2:11:57 PM	31.03
19-Sep-2002	1:58:27 PM	20-Sep-2002	10:01:21 AM	20.05
1-Oct-2002	8:05:08 AM	1-Oct-2002	2:48:47 PM	6.73
10-Oct-2002	7:43:15 AM	10-Oct-2002	2:42:19 PM	6.98
14-Oct-2002	8:06:17 AM	15-Oct-2002	11:05:37 AM	26.99
12-Nov-2002	3:19:26 PM	13-Nov-2002	7:16:51 AM	15.96
21-Nov-2002	2:36:45 PM	26-Nov-2002	7:23:15 AM	112.78
2-Dec-2002	10:47:15 AM	2-Dec-2002	3:17:15 PM	4.5
9-Dec-2002	6:15:52 AM	10-Dec-2002	2:11:52 AM	19.93
15-Dec-2002	10:51:16 PM	16-Dec-2002	2:54:24 PM	16.05
19-Dec-2002	7:30:19 AM	20-Dec-2002	11:14:18 AM	27.73
23-Dec-2002	1:35:08 PM	24-Dec-2002	7:03:01 AM	17.46
26-Dec-2002	11:41:56 AM	30-Dec-2002	7:06:56 AM	91.42
30-Dec-2002	8:05:04 AM	31-Dec-2002	10:05:35 AM	26.01
6-Jan-2003	10:09:59 AM	7-Jan-2003	7:04:33 AM	20.91
13-Mar-2003	4:16:20 AM	14-Mar-2003	11:02:42 AM	30.77
11-Apr-2003	9:38:56 AM	16-Apr-2003	10:24:00 AM	120.75
19-May-2003	1:39:51 PM	20-May-2003	7:20:08 AM	17.67
28-May-2003	2:59:38 PM	29-May-2003	7:15:00 AM	16.26
11-Jul-2003	12:37:42 PM	15-Jul-2003	1:23:45 PM	96.77
22-Jul-2003	10:09:20 AM	23-Jul-2003	8:23:41 AM	22.24
2-Oct-2003	11:20:37 AM	3-Oct-2003	9:00:28 AM	21.66
	Total Down Time:			818.77

APPENDIX F. Individual fish histories obtained during this study.

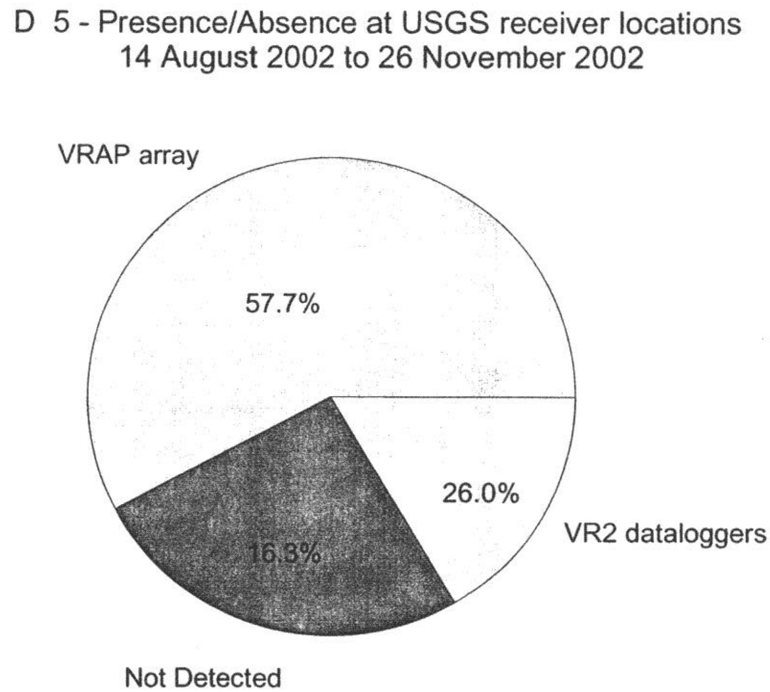
The following pages depict location and depth data collected on individual white sturgeon tagged in this study. The histories are comprised of three graphics for most fish and two for fish without pressure-sensing transmitters. The first shows the period of residence in the positioning array and movements to and from the array as noted by the acoustic receiver gates. The second graphic illustrates depths occupied by those fish carrying pressure sensors. Depth histories are quite detailed because depth data was available from the data-logging acoustic gates as well as the positioning array. Location and depth profile histories began when the fish was released and end on the last day it was detected. The total number of detections with each receiver type is shown in Table 3 of the main report. Locations of individual VR2 receivers and the VRAP array buoys are shown in Figure 1 of the main report. Characteristics of white sturgeon tagged are presented in Tables 2 and 3.

The third graphic is an indicator of fidelity to the study area. The pie graphs illustrate the proportion of time each fish spent within the positioning (VRAP) array, the time it was detected elsewhere (at any of the acoustic gates) and the time that it was not detected at any of the USGS receivers. Each pie graph for 2002 encompasses the time beginning when the fish was released until 26 November when the last fish departed the study area. For 2003, the time period began either when a fish tagged in 2002 returned to the study area or when a fish tagged in 2003 was initially released, and ended on 13 October when the telemetry array was dismantled.

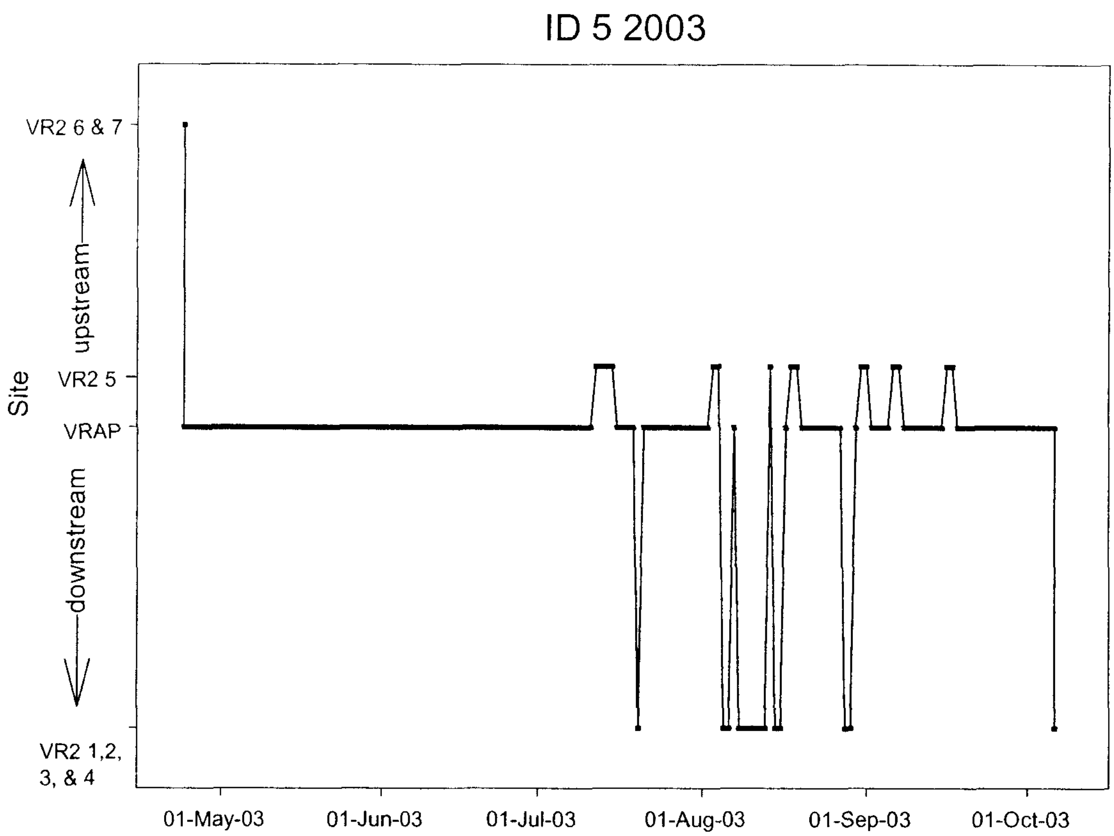
Histories for the 19 fish tagged in 2002 are separated into two time periods. All of these fish dispersed away from our receivers by the end of November 2002 and did not return until April 2003, providing a temporal break in the data for these fish.

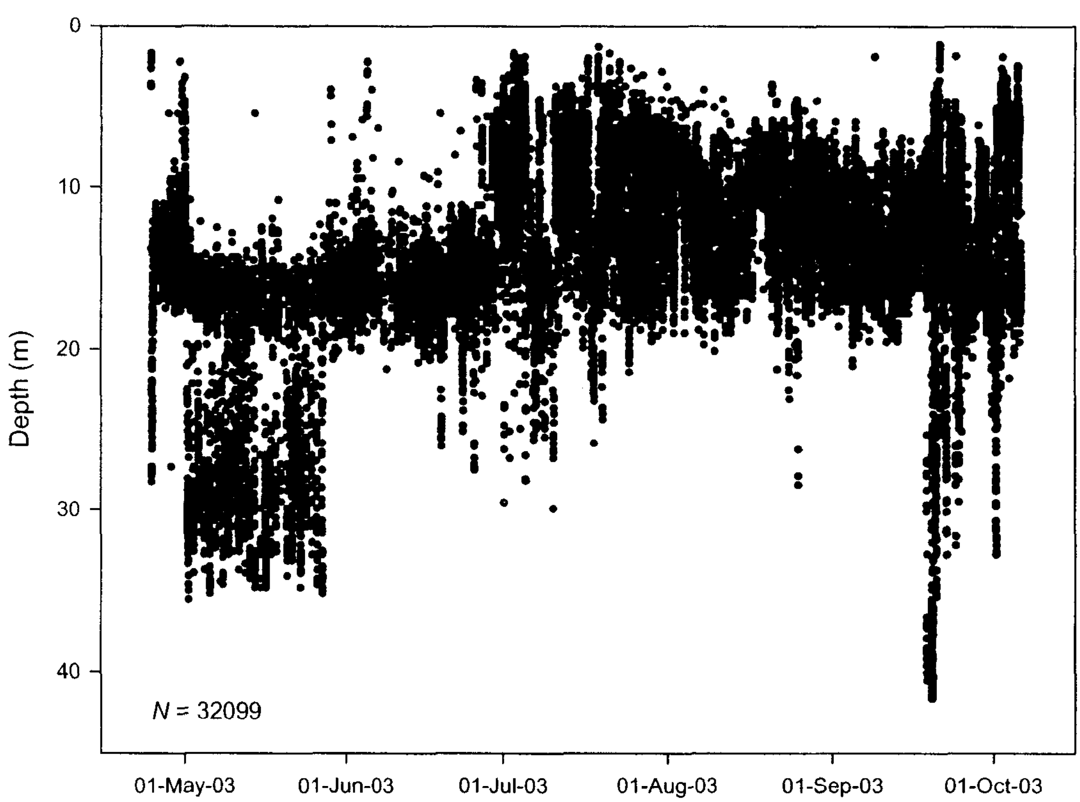

ID 5 2002
VR2 6 & 7
upstream
VR2 5
Site
VRAP
downstream
VR2 1,2, 3, & 4
05-Aug-02
19-Aug-02
02-Sep-02
16-Sep-02
30-Sep-02
14-Oct-02
28-Oct-02
11-Nov-02
0
10
20
30
40
Depth (m)
N = 7097
05-Aug-02
19-Aug-02
02-Sep-02
16-Sep-02
30-Sep-02
14-Oct-02
28-Oct-02
11-Nov-02

Appendix F continued.



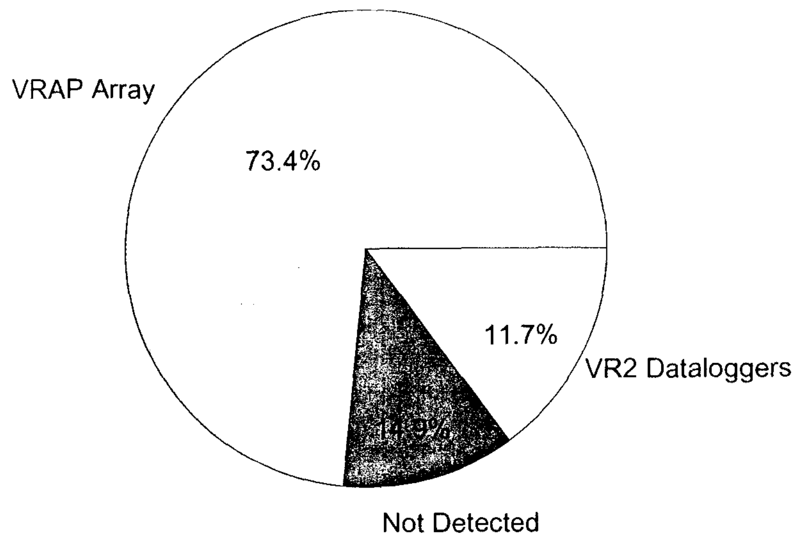
Appendix F continued.



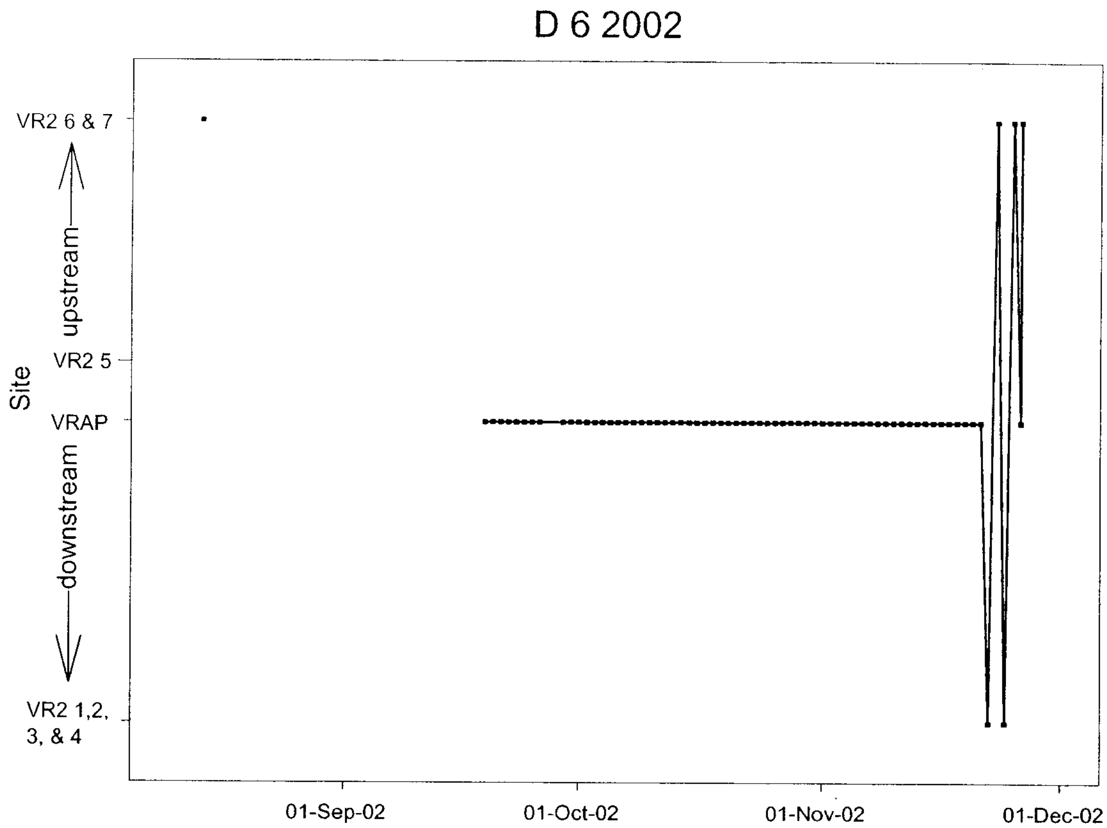


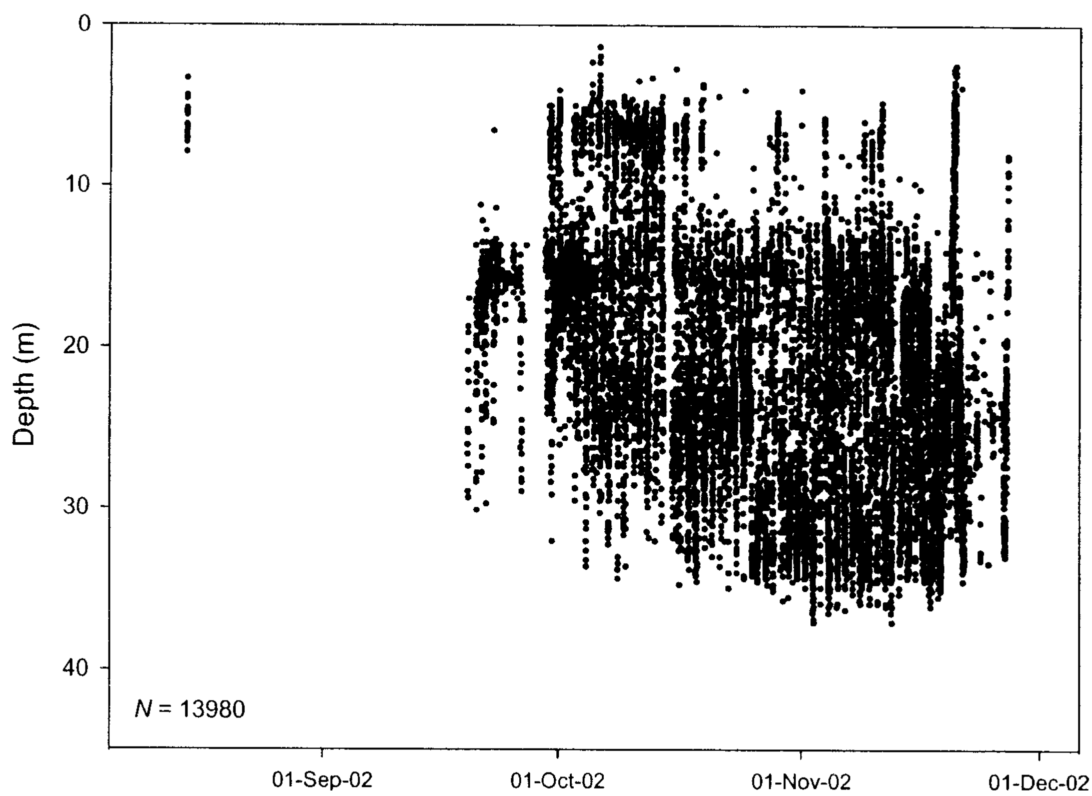
Appendix F continued.

D 5 - 2003 Presen ce/Absence at USGS receiver locations
8 April 2003 - 13 October 2003



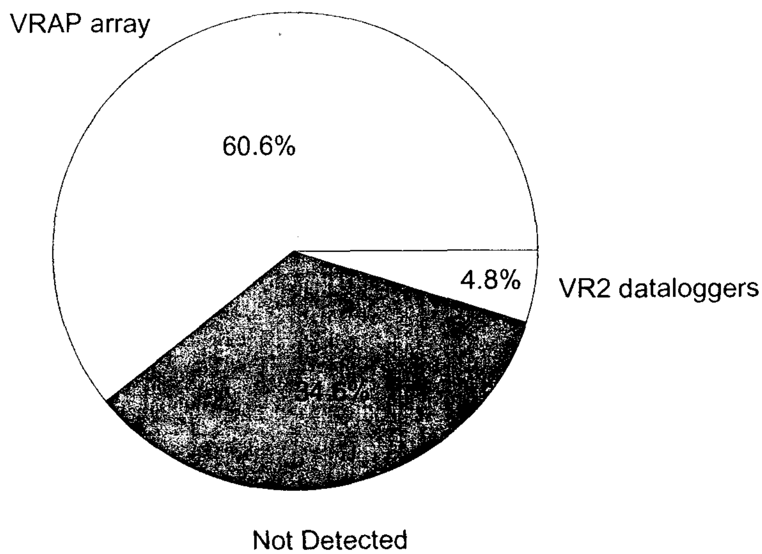
Appendix F continued.



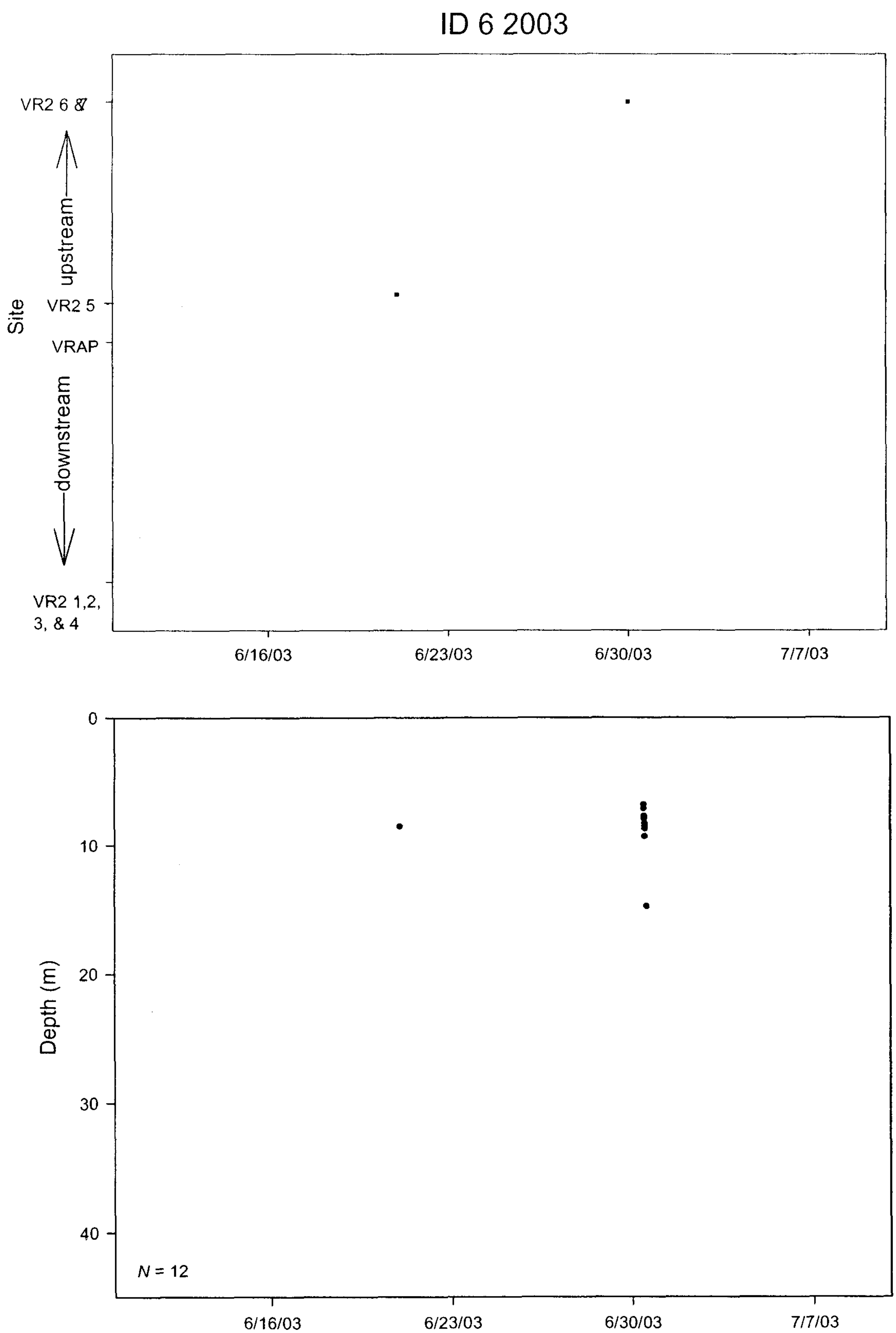


Appendix F continued.

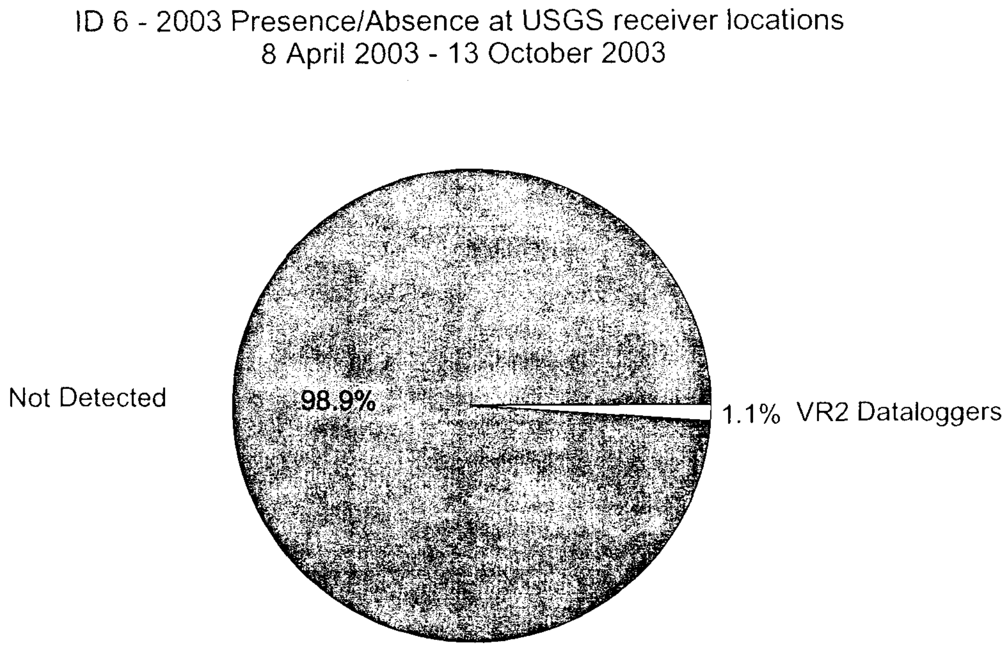
D 6 - Presence/Absence at USGS receiver locations
14 August 2002 to 26 November 2002

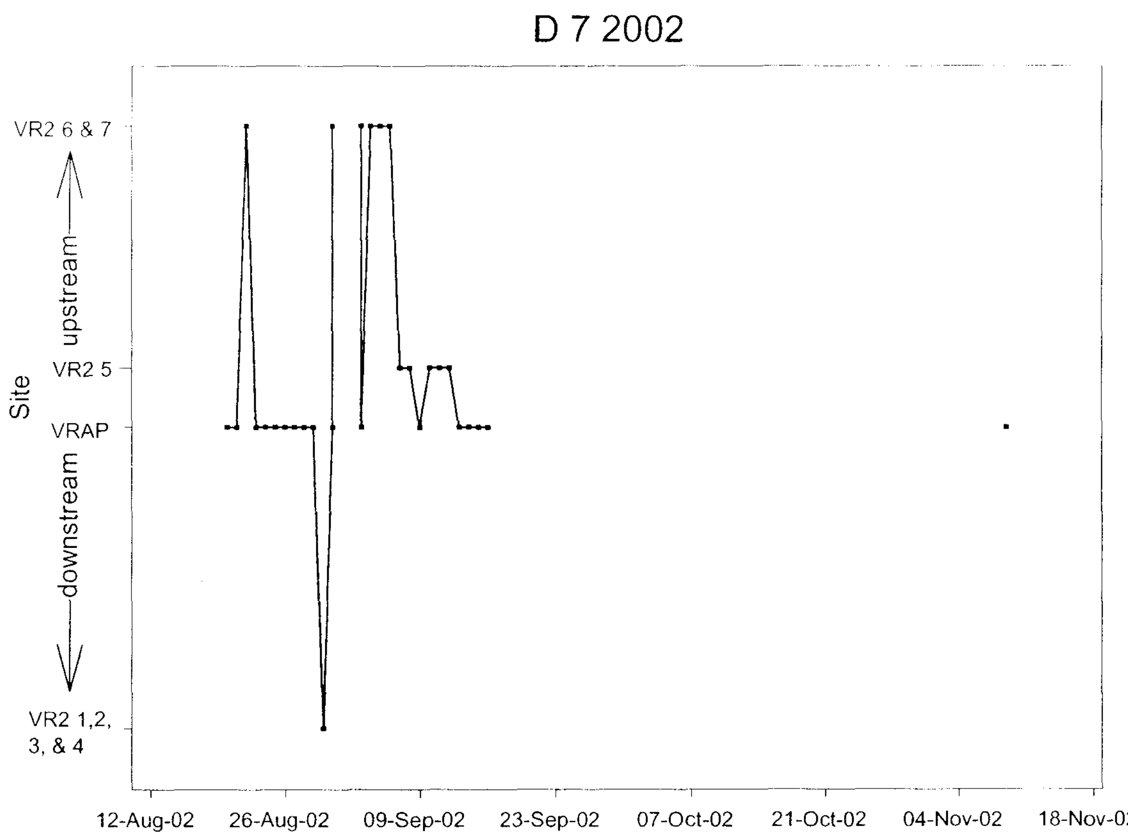


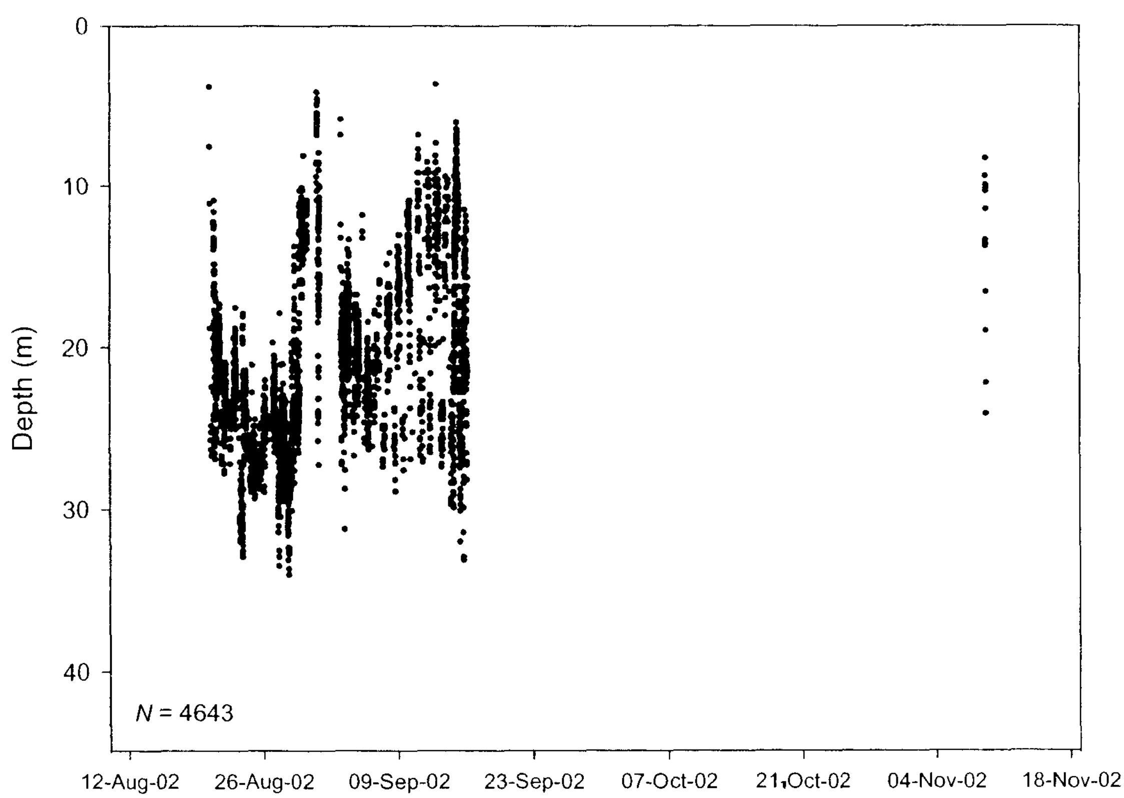
Appendix F continued.



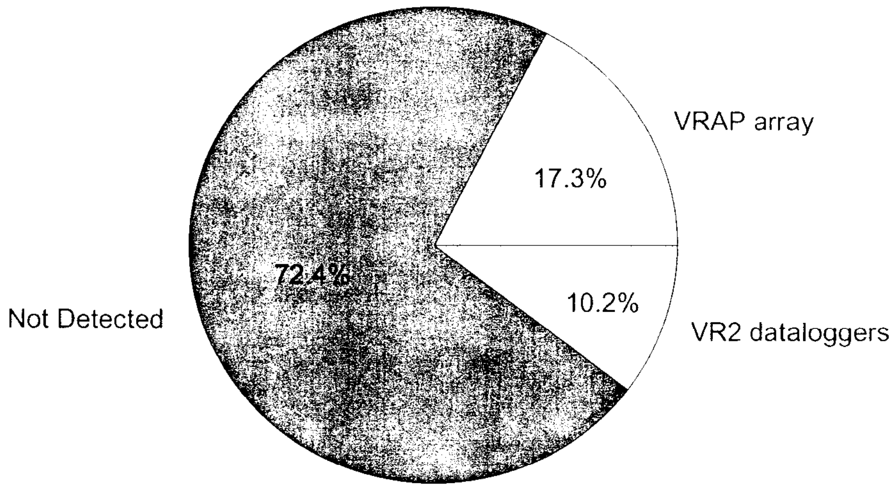
Appendix F continued.



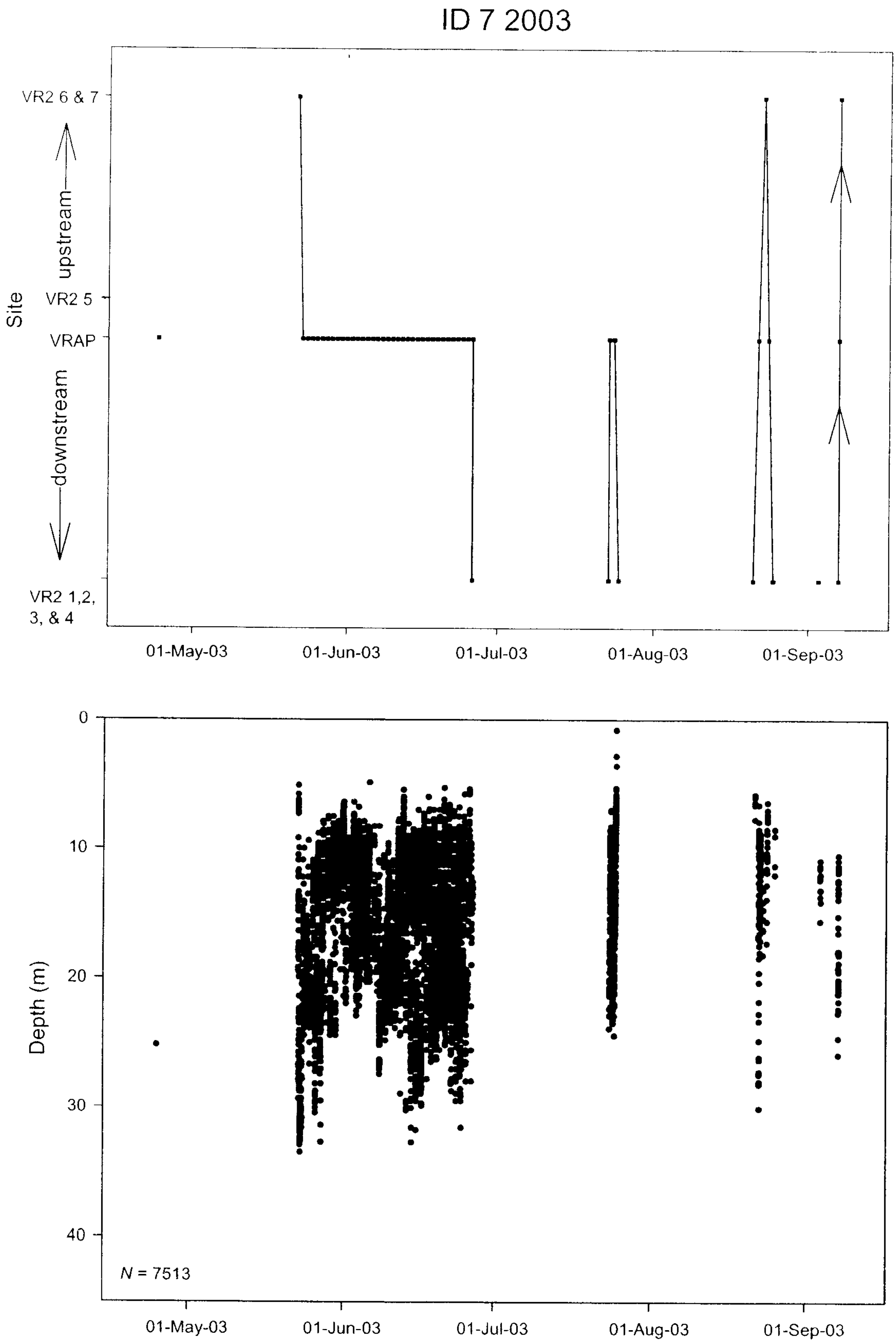

D 7 2002
VR2 6 & 7
upstream
Site
VR2 5
VRAP
downstream
VR2 1,2, 3, & 4
12-Aug-02
26-Aug-02
09-Sep-02
23-Sep-02
07-Oct-02
21-Oct-02
04-Nov-02
18-Nov-02


0
10
20
30
40
Depth (m)
N = 4643
12-Aug-02
26-Aug-02
09-Sep-02
23-Sep-02
07-Oct-02
21-Oct-02
04-Nov-02
18-Nov-02

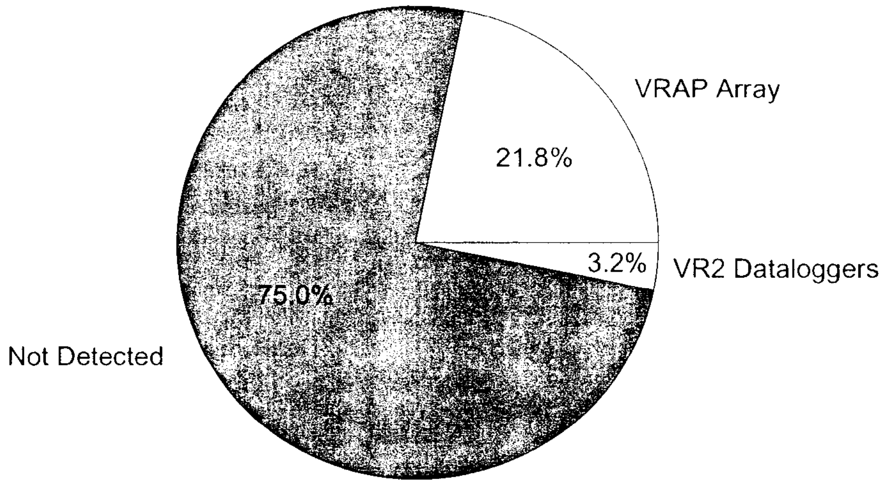
D 7 - Presen ce/Absence at USGS receiver locations
20 August 2002 to 26 November 2002



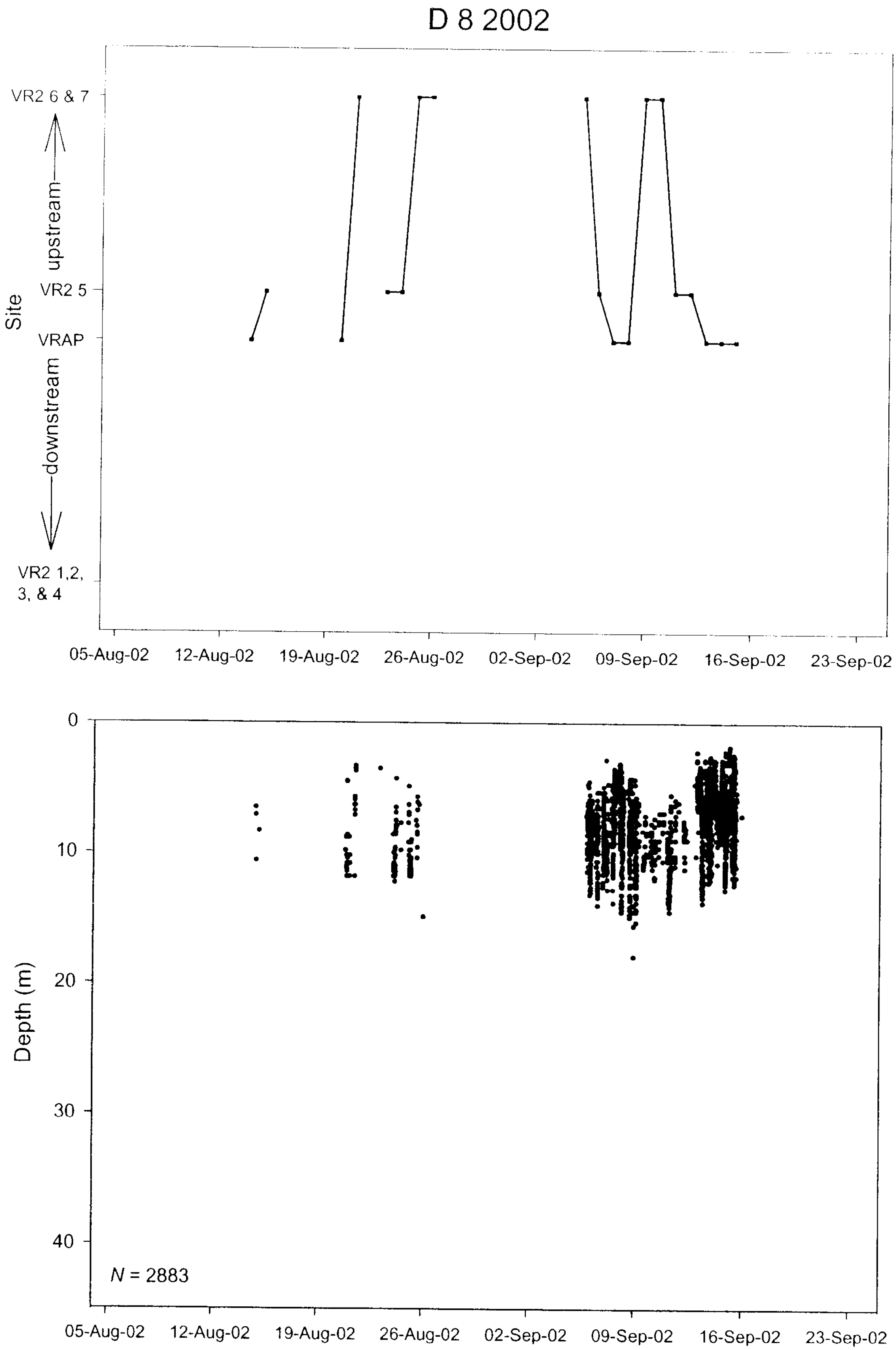
Appendix F continued.



D 7 - 2003 Pre sence/Absence at USGS receiver locations
8 April 2003 - 13 October 2003

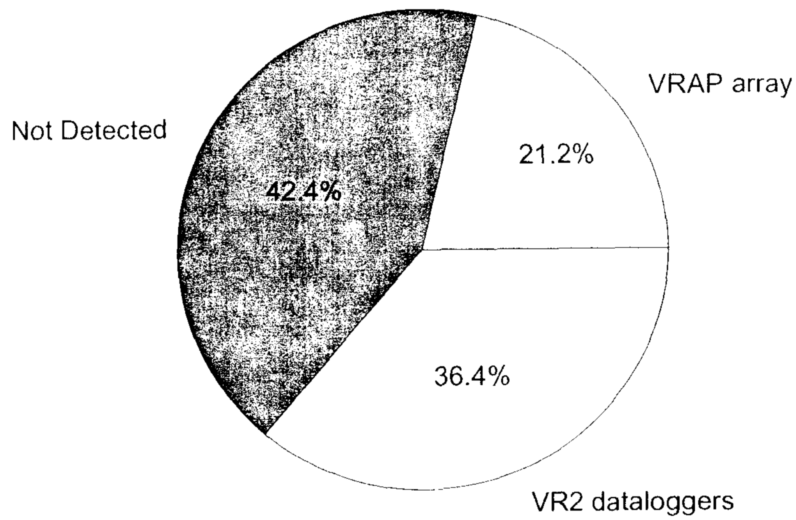


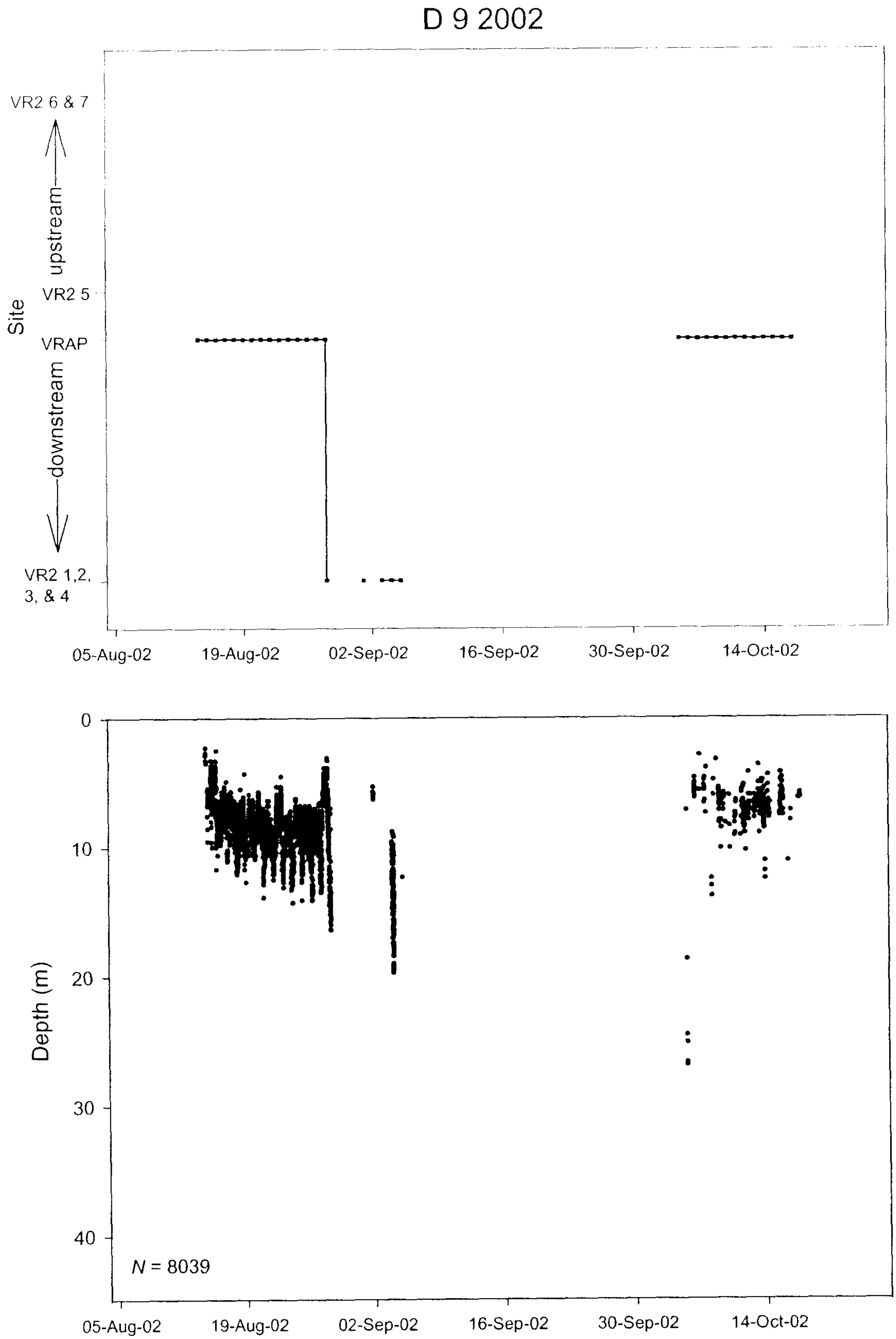
Appendix F continued.



Appendix F continued.

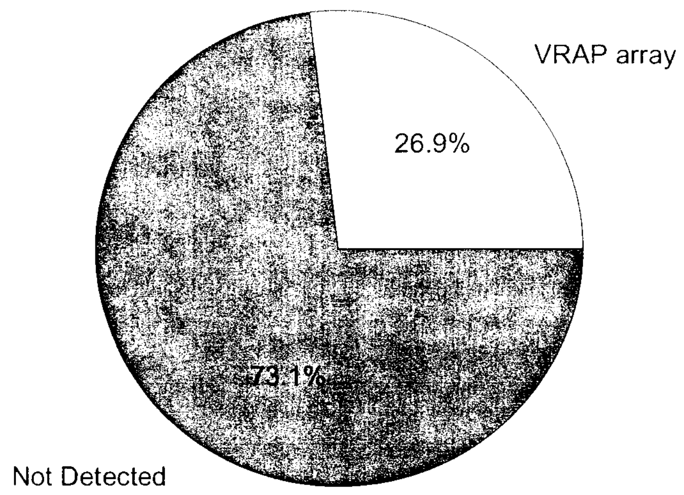
ID 8 - Presence/Absence at USGS receiver locations
14 August 2002 to 15 September 2002



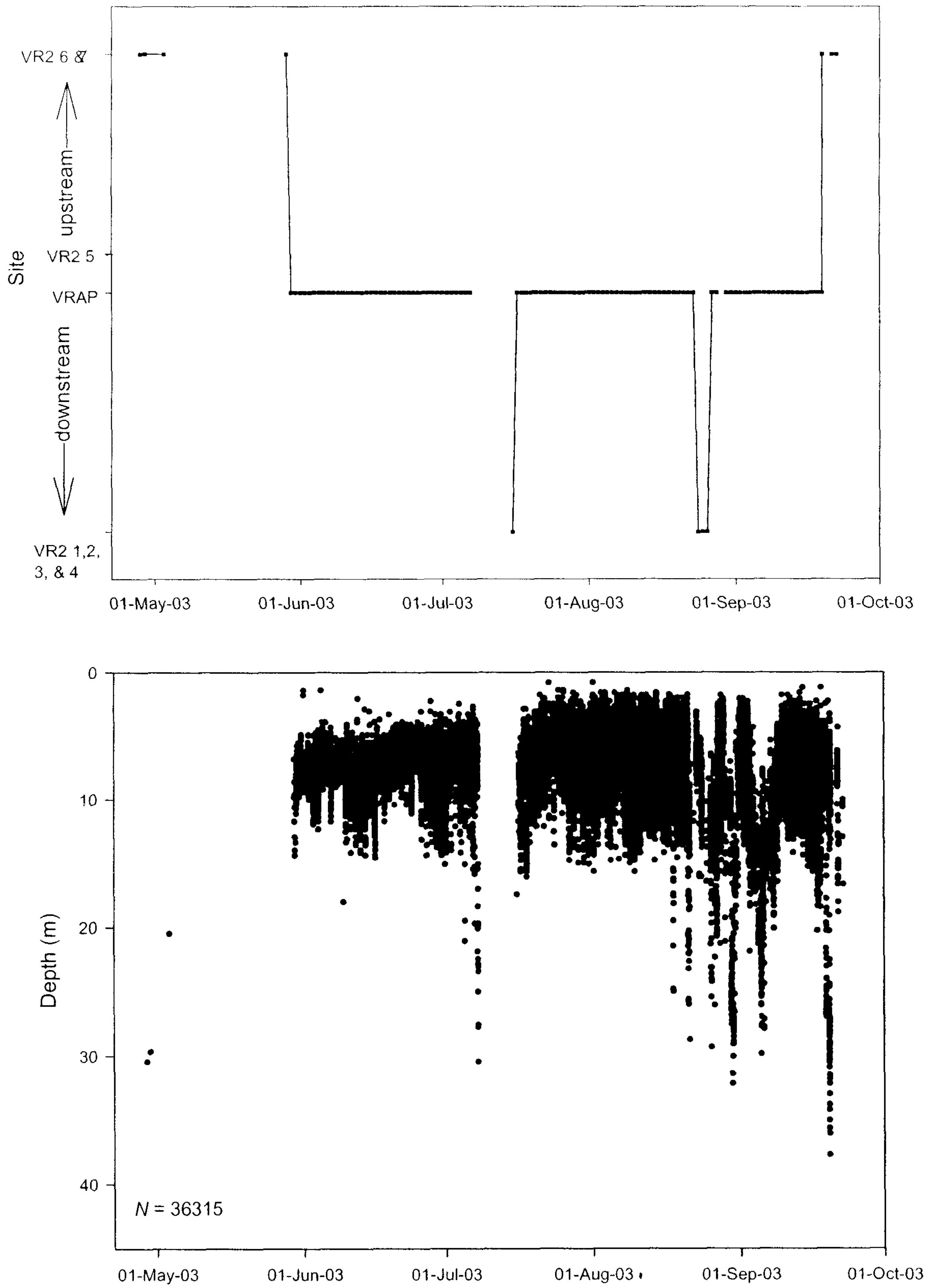

D 9 2002
VR2 6 & 7
upstream
VR2 5
Site
VRAP
downstream
VR2 1,2, 3, & 4
05-Aug-02
19-Aug-02
02-Sep-02
16-Sep-02
30-Sep-02
14-Oct-02
0
10
20
30
40
Depth (m)
N = 8039
05-Aug-02
19-Aug-02
02-Sep-02
16-Sep-02
30-Sep-02
14-Oct-02

Appendix F continued.

ID 9 - Presence/Absence at USGS receiver locations
14 August 2002 to 26 November 2002



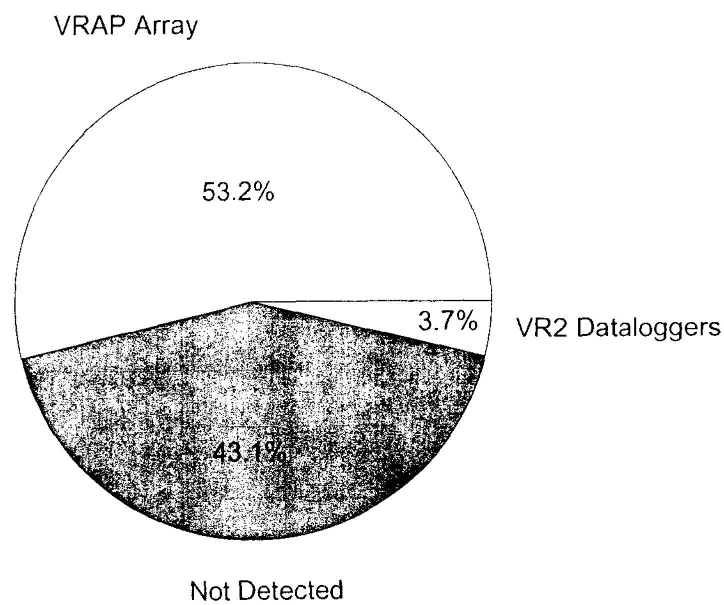
ID 9 2003



VR2 6 & 7
upstream
Site
VR2 5
VRAP
downstream
VR2 1,2, 3, & 4
01-May-03
01-Jun-03
01-Jul-03
01-Aug-03
01-Sep-03
01-Oct-03
0
10
20
30
40
Depth (m)
N = 36315
01-May-03
01-Jun-03
01-Jul-03
01-Aug-03
01-Sep-03
01-Oct-03

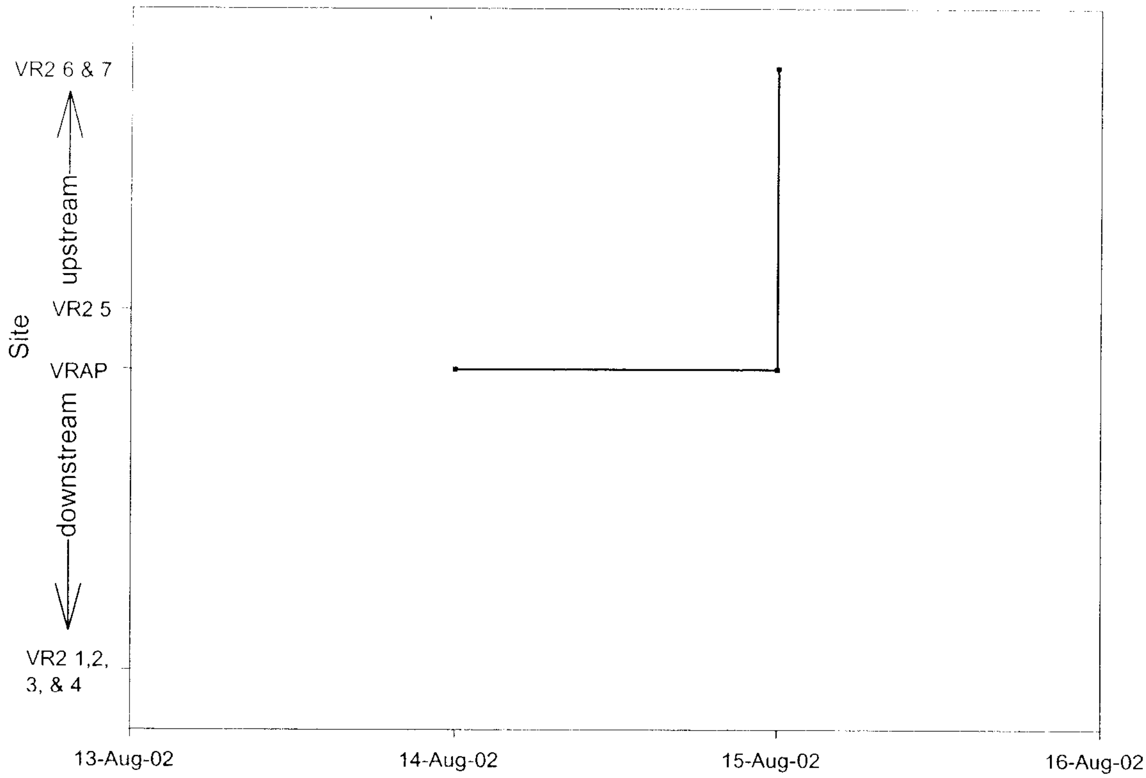
Appendix F continued.

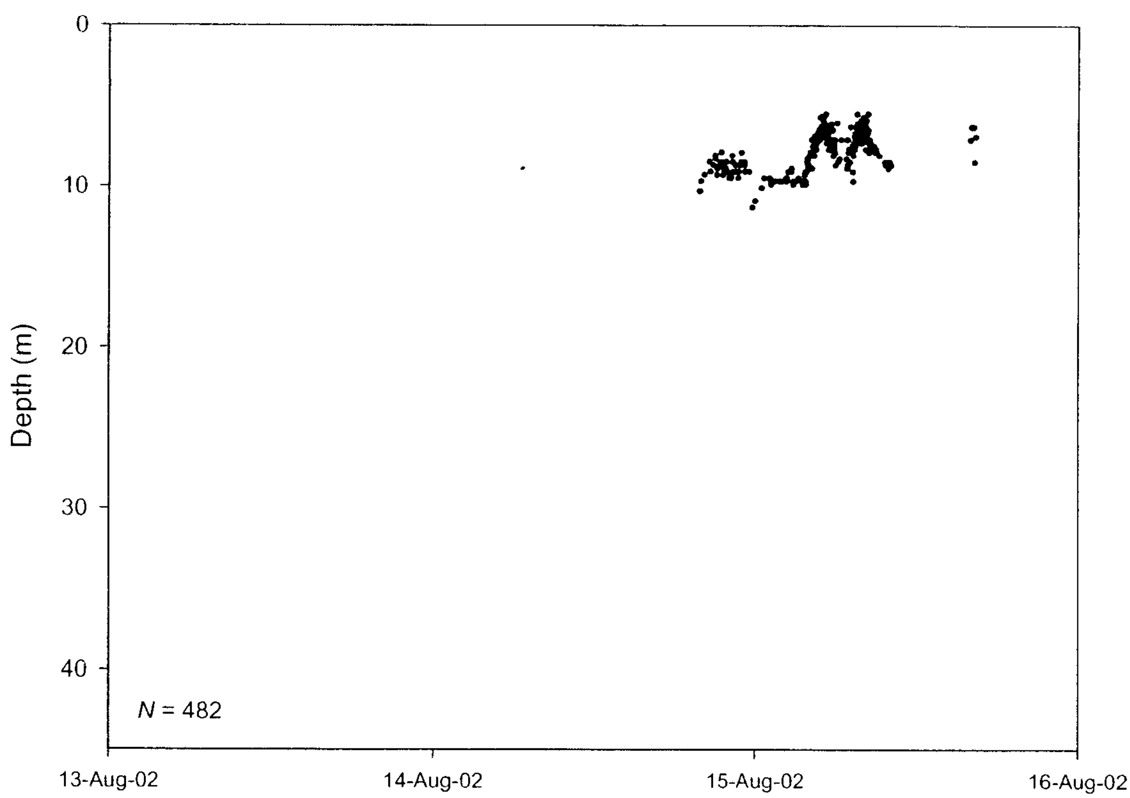
D 9 - 2003 Presence/Absence at USGS receiver locations
8 April 2003 - 13 October 2003



Appendix F continued.

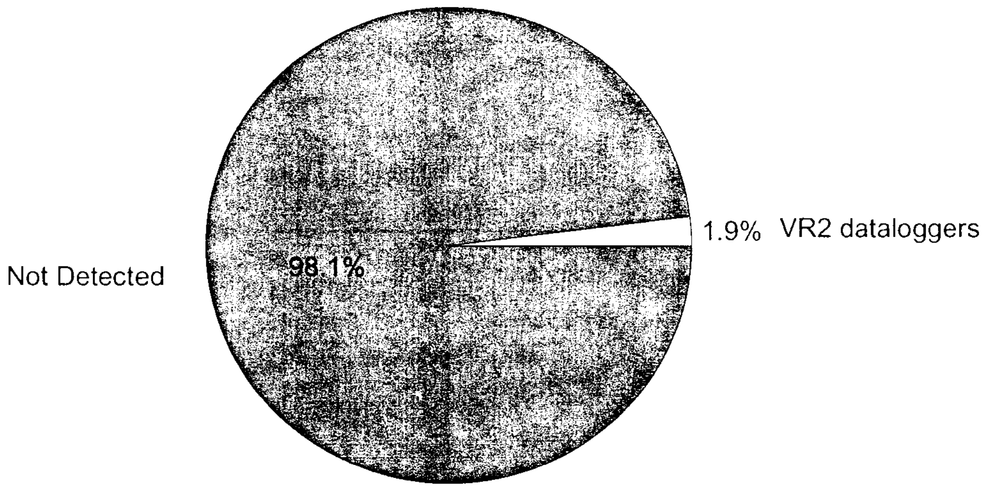
ID 10 2002





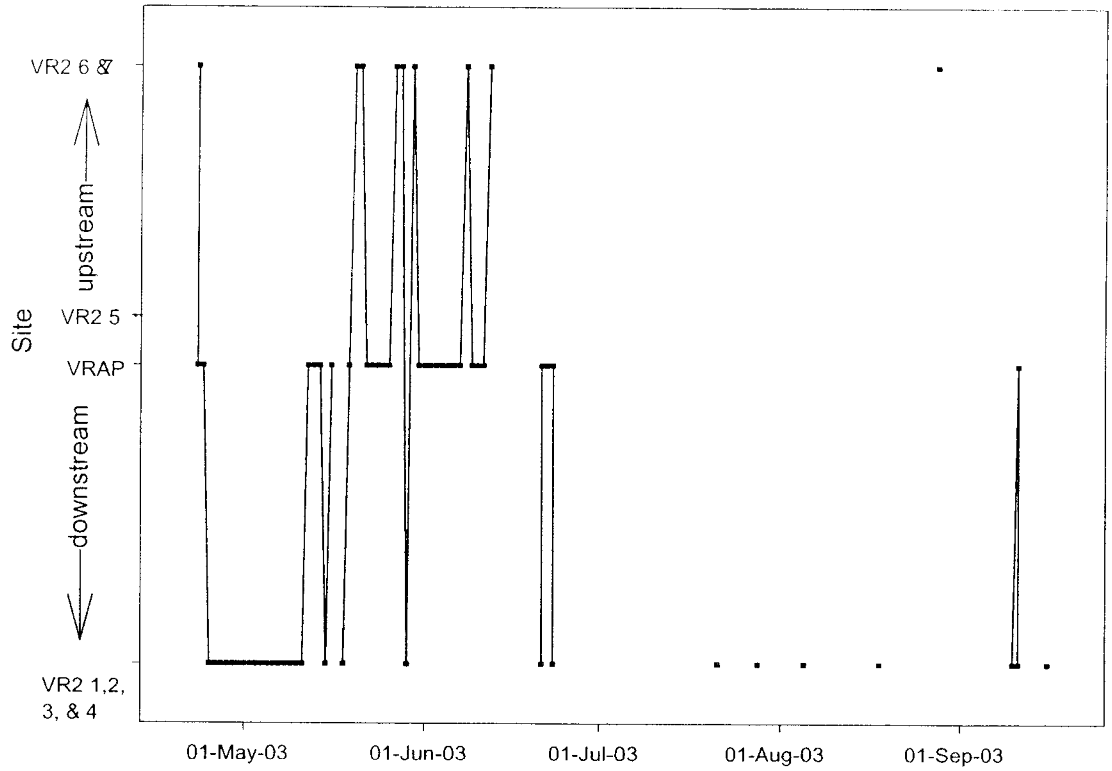
Appendix F continued.

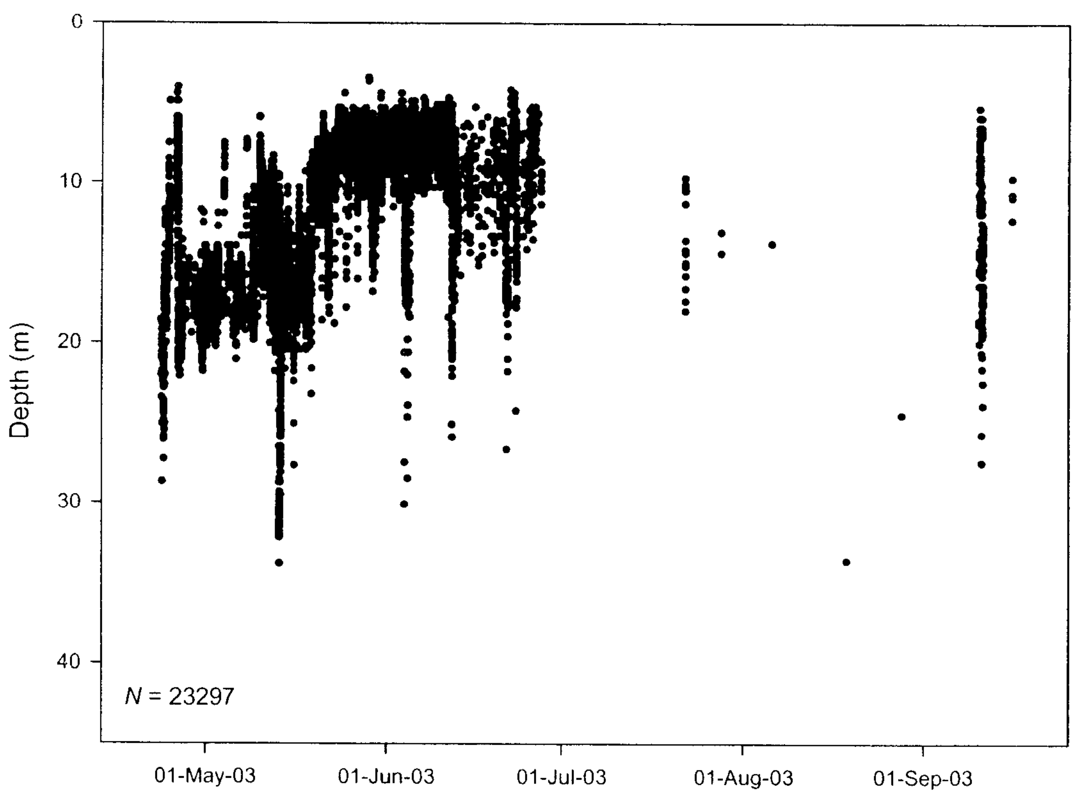
D 10 - Presence/Absence at USGS receiver locations
14 August 2002 to 26 November 2002



Appendix F continued.

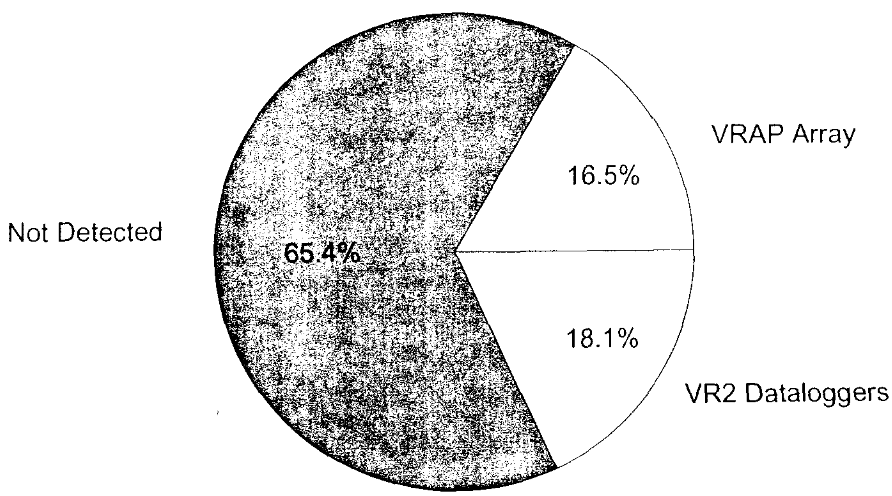
D 10 2003



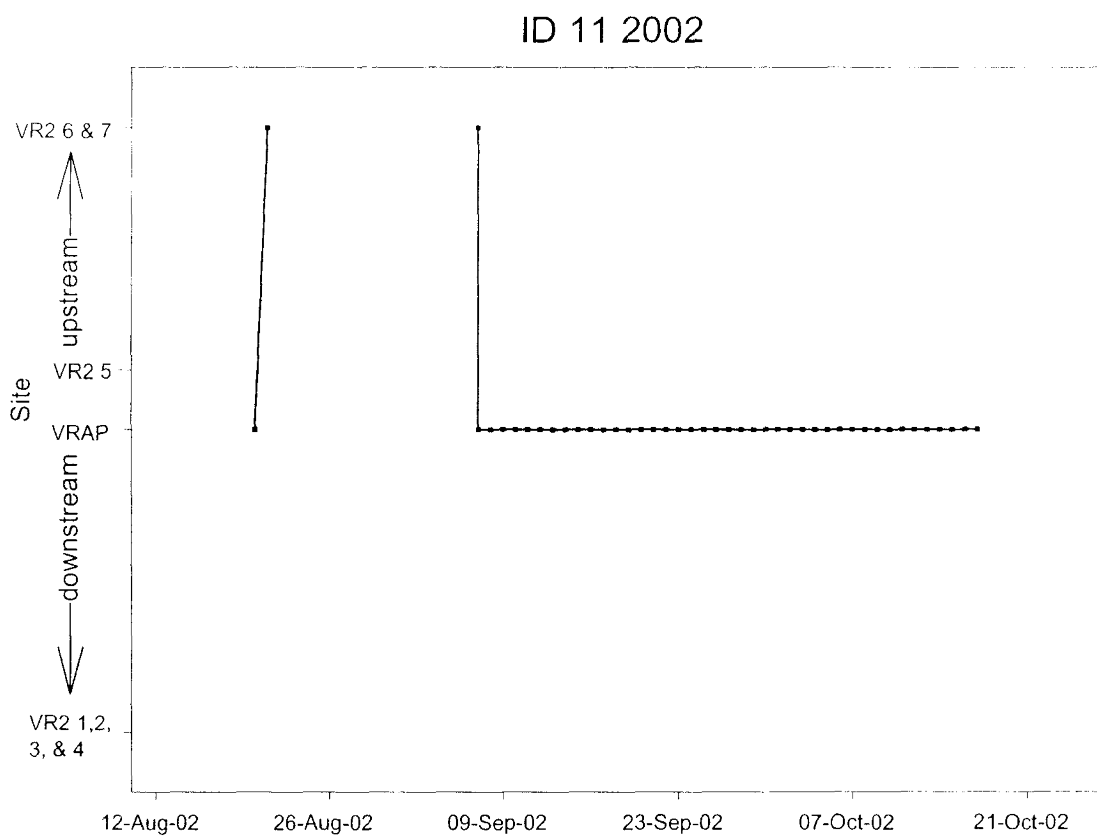


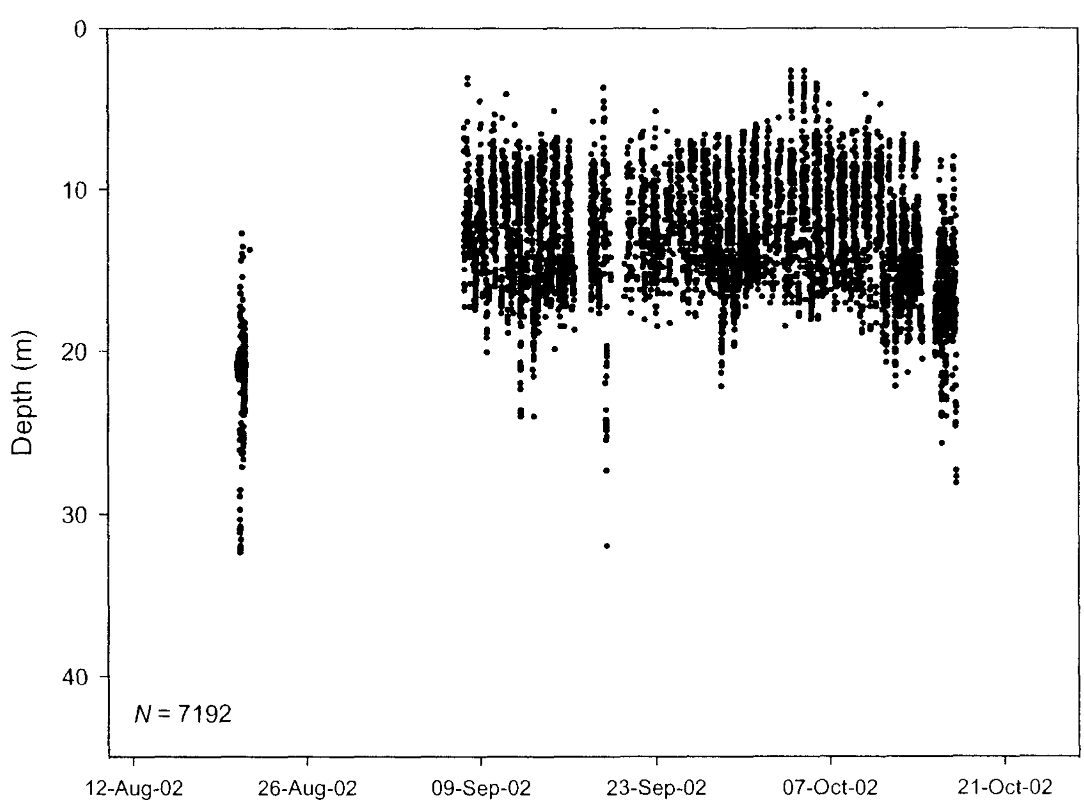
Appendix F continued.

ID 10 - 2003 Presence/Absence at USGS receiver locations
8 April 2003 - 13 October 2003



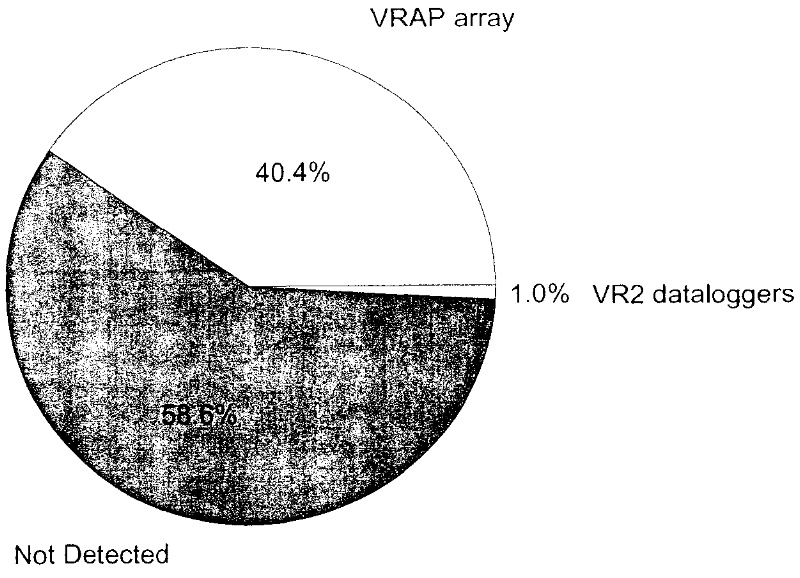
Appendix F continued.

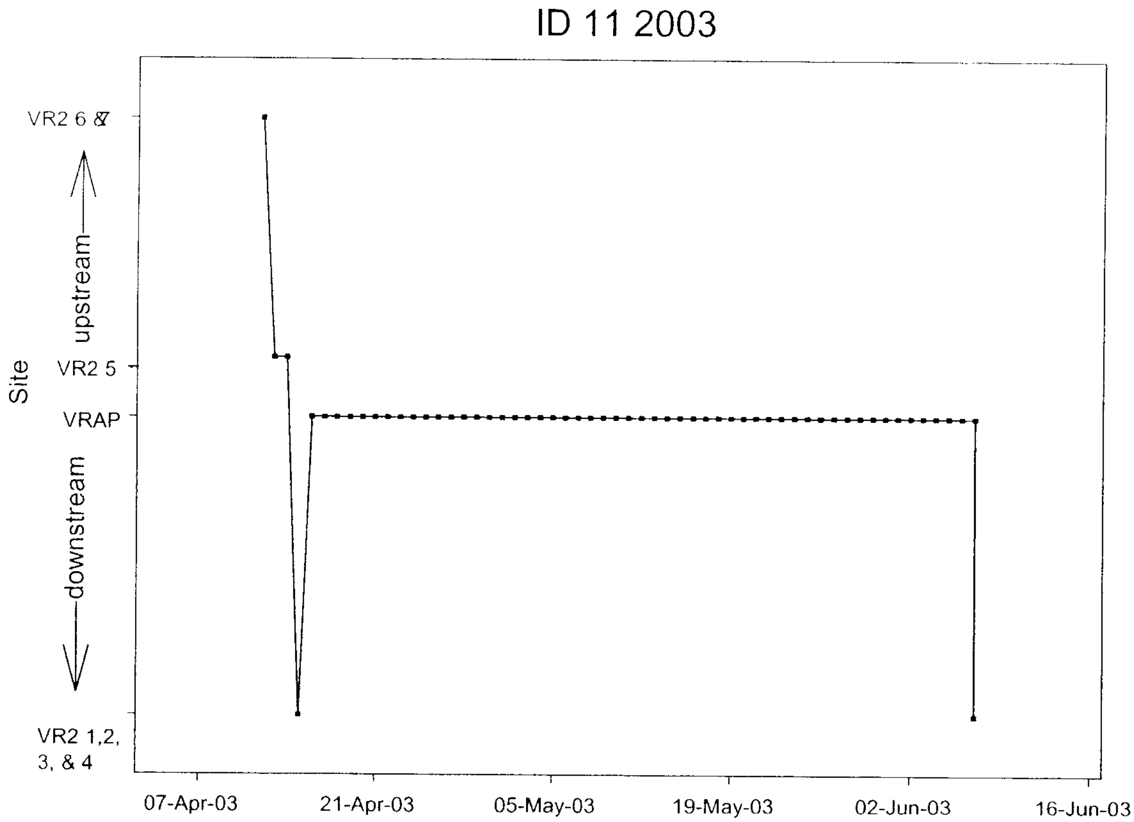


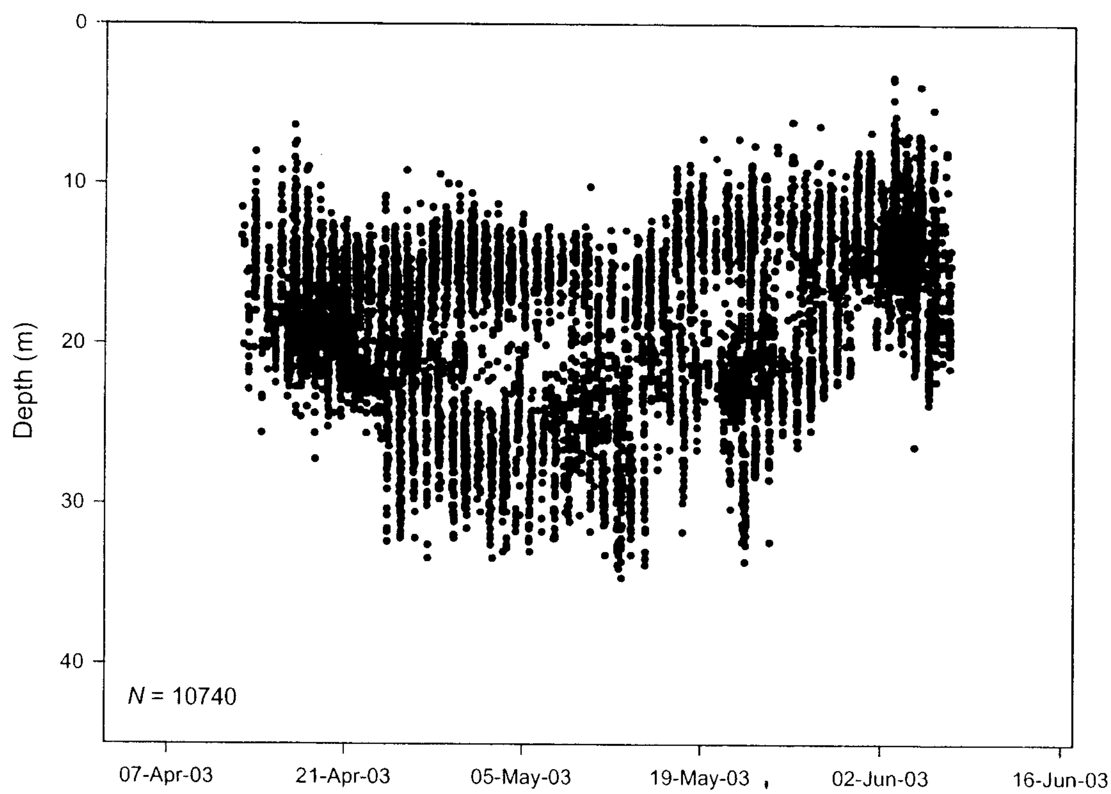


Appendix F continued.

D 11 - Presence/Absence at USGS receiver locations
20 August 2002 to 26 November 2002

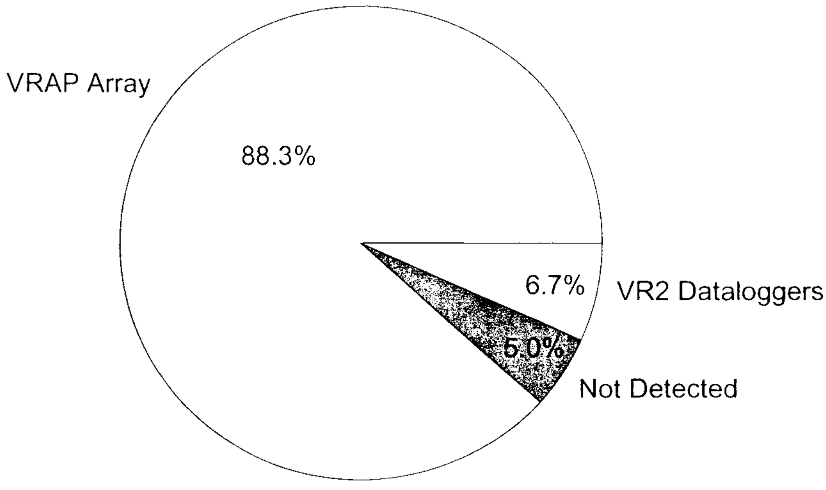



ID 11 2003
VR2 6 & 7
upstream
Site
VR2 5
VRAP
downstream
VR2 1,2, 3, & 4
07-Apr-03
21-Apr-03
05-May-03
19-May-03
02-Jun-03
16-Jun-03

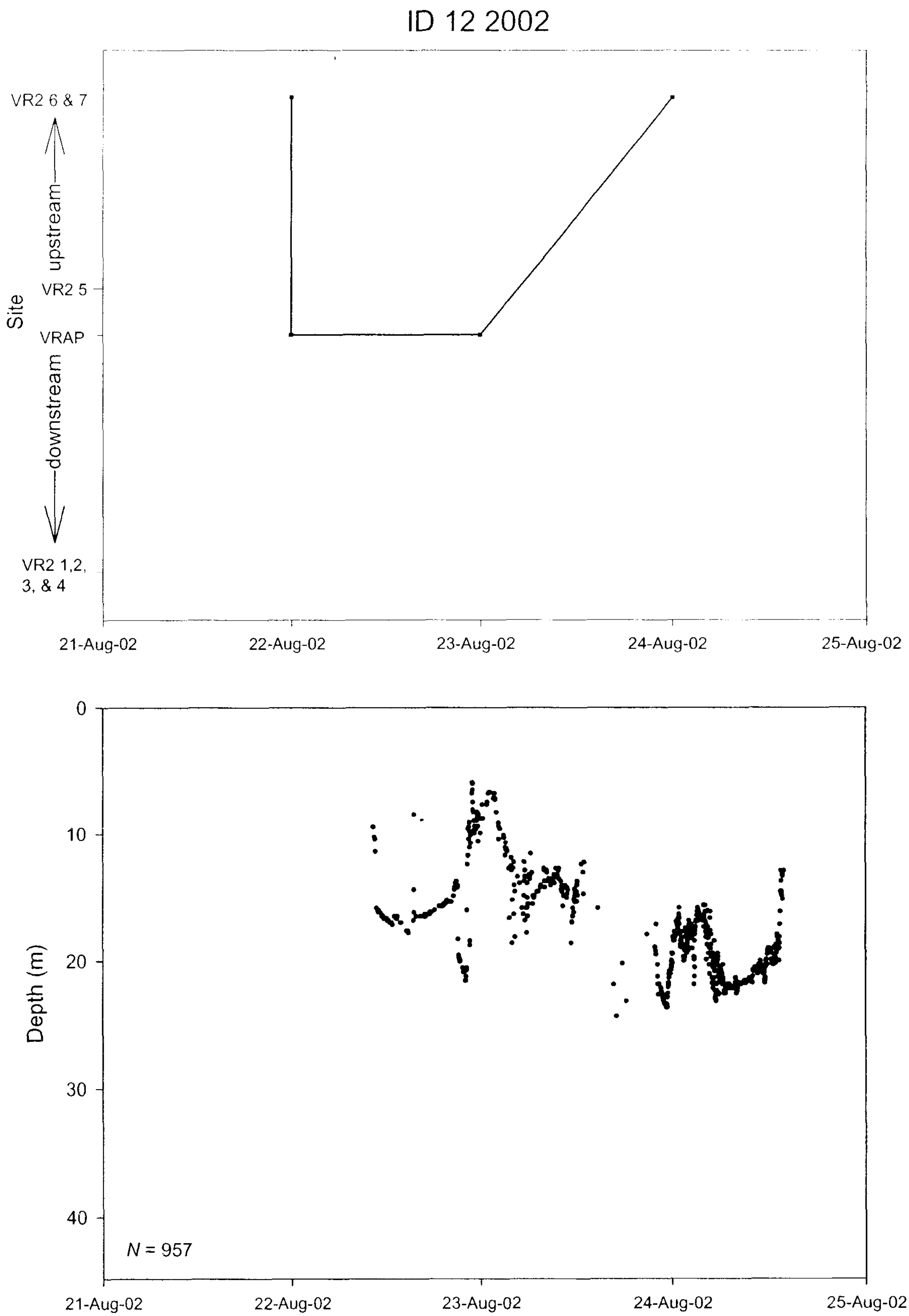

0
10
20
30
40
Depth (m)
N = 10740
07-Apr-03
21-Apr-03
05-May-03
19-May-03
02-Jun-03
16-Jun-03

Appendix F continued.

D 11 - 2003 Presen ce/Absence at USGS receiver locations
8 April 2003 - 13 October 2003

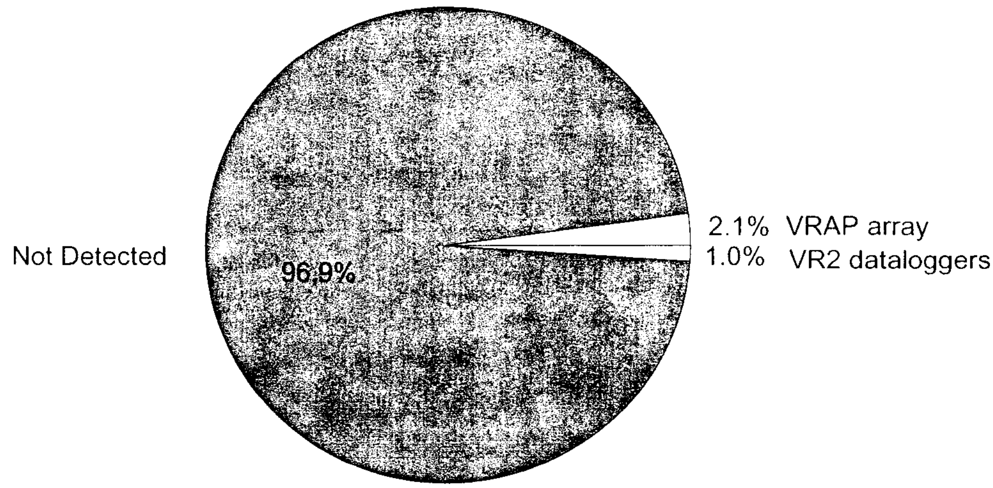


Appendix F continued.

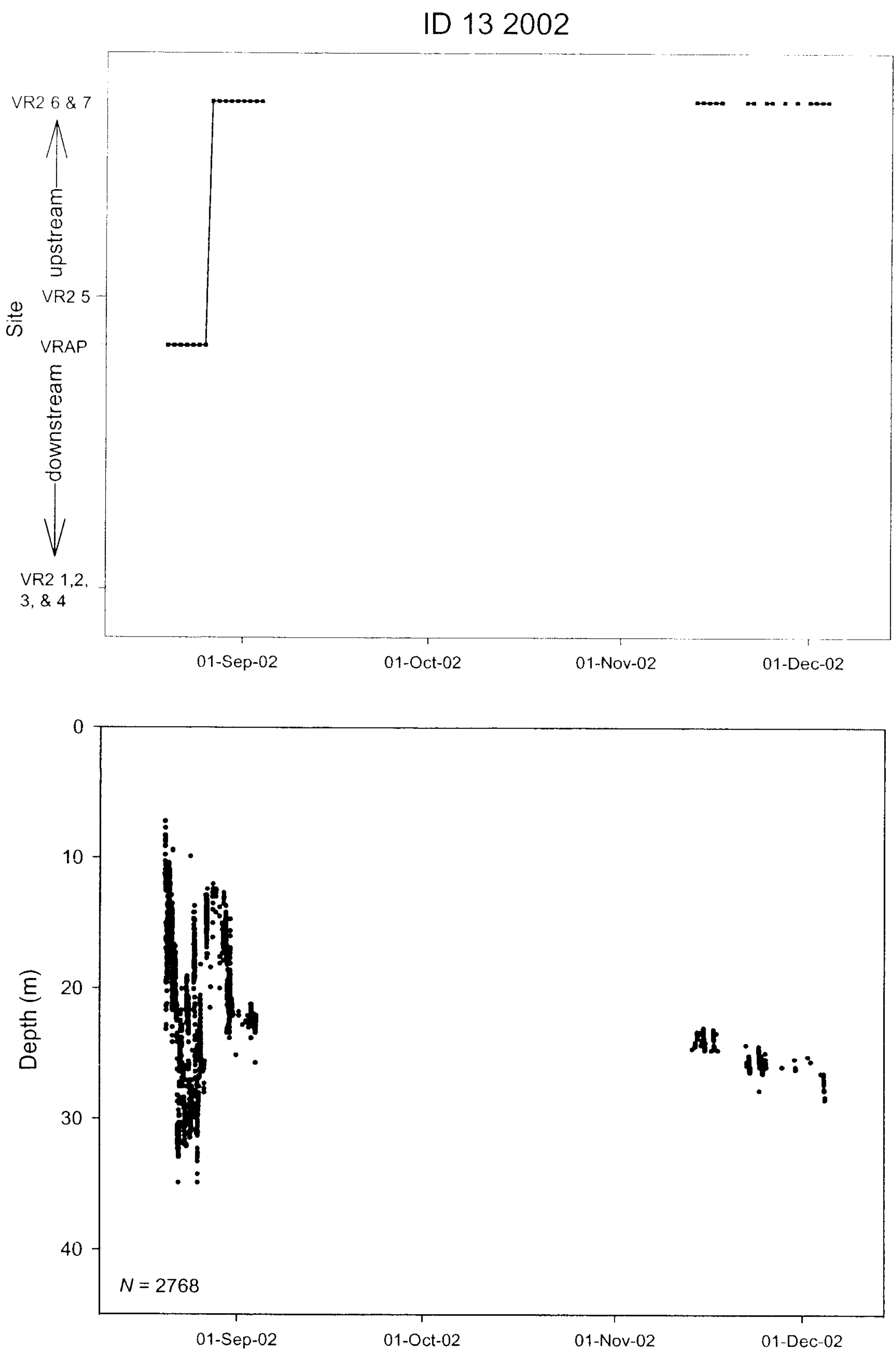


Appendix F continued.

D 1 2 - Presence/Absence at USGS receiver locations
22 August 2002 to 26 November 2002

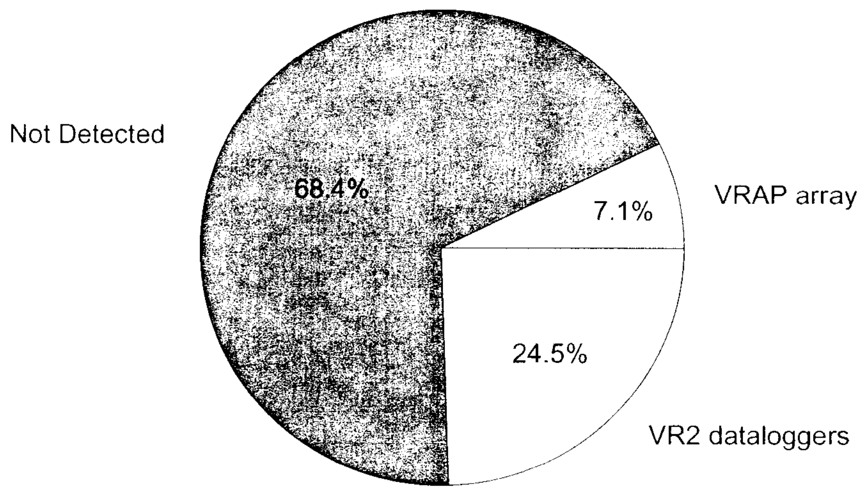


Appendix F continued.

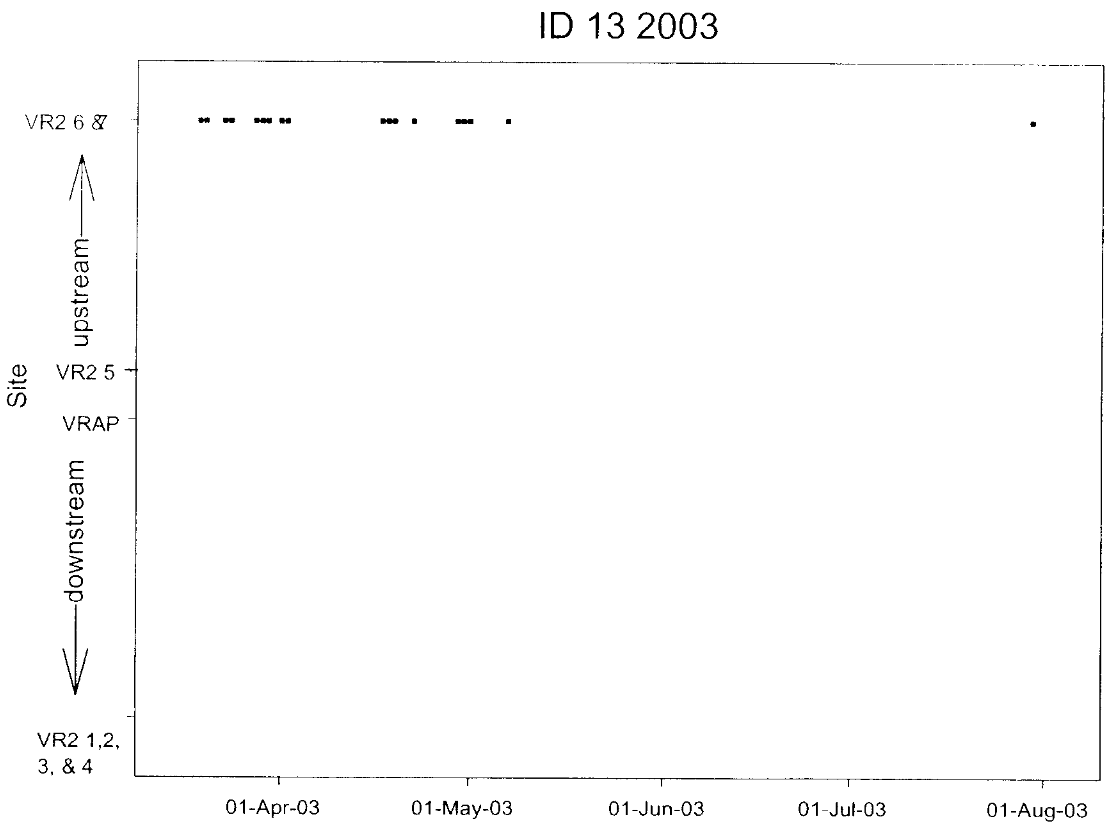


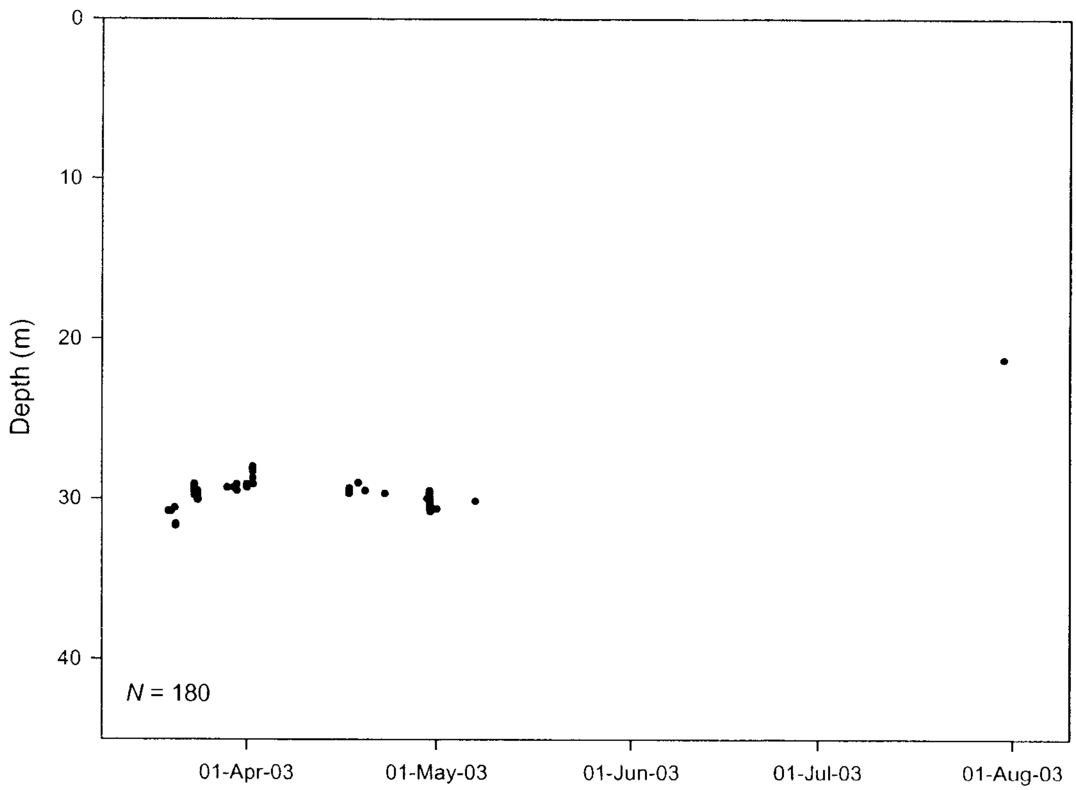
Appendix F continued.

D 13 - Presence/Absence at USGS receiver locations
20 August 2002 to 26 November 2002



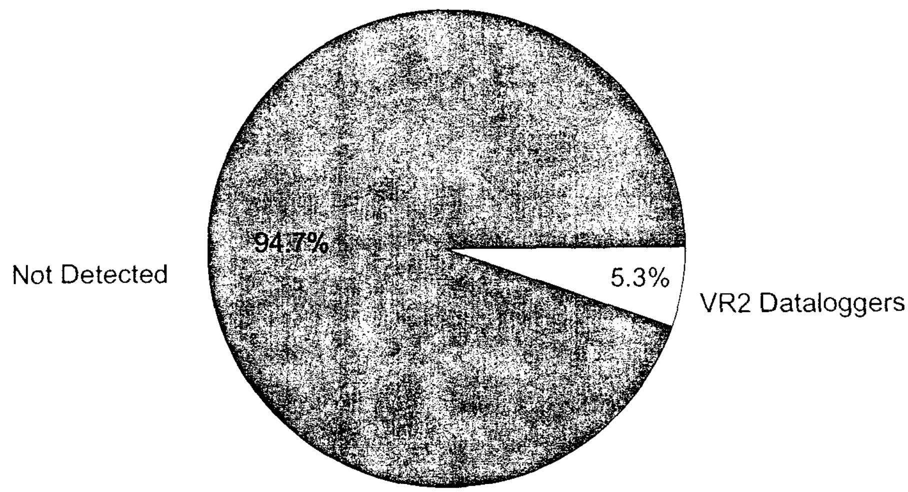
Appendix F continued.



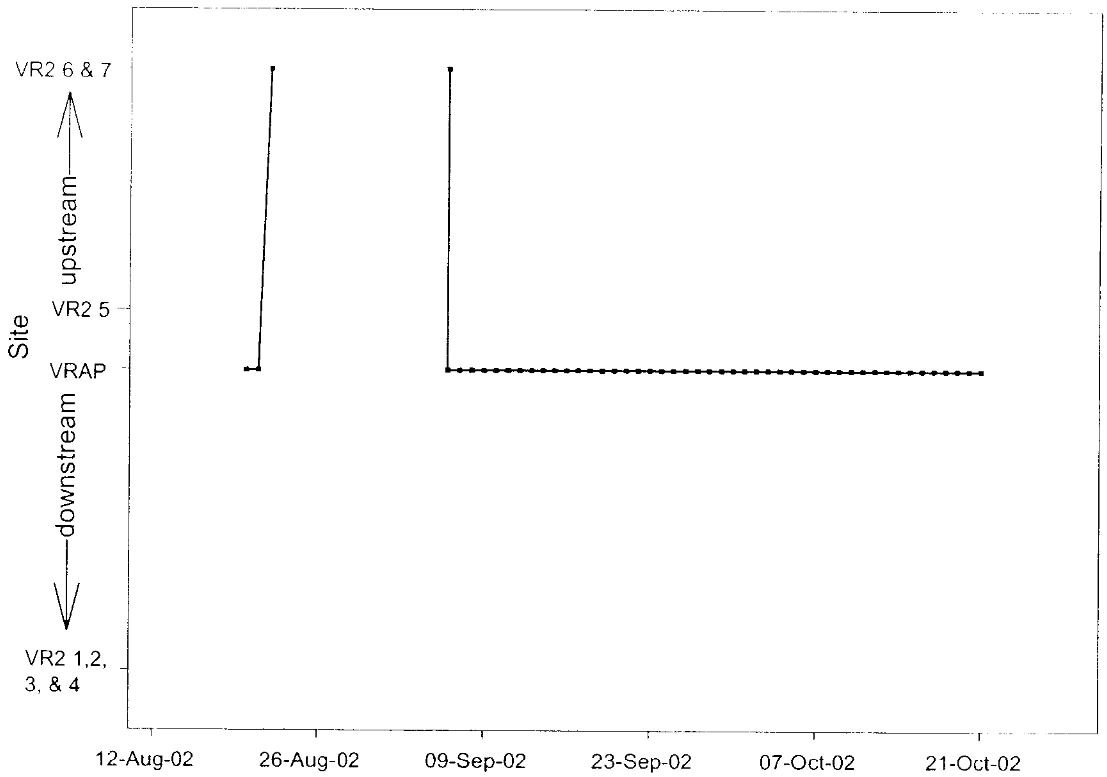


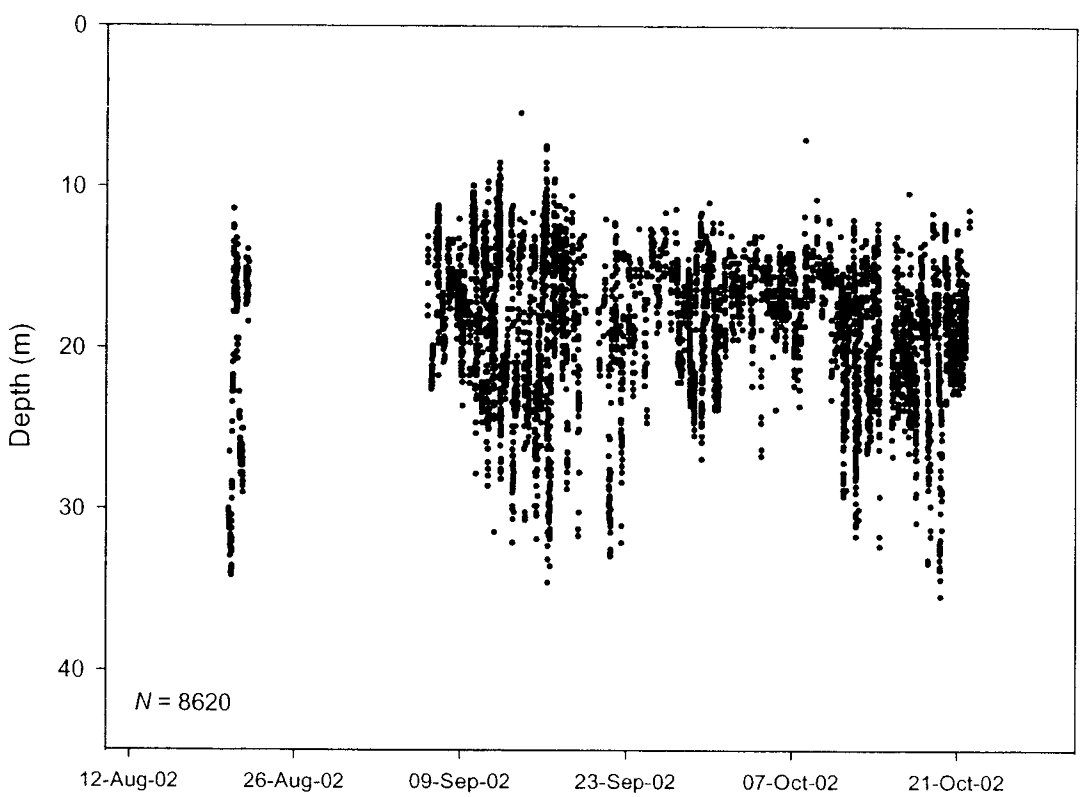
Appendix F continued.

ID 13 - 2003 Presence/Absence at USGS receiver locations
8 April 2003 - 13 October 2003



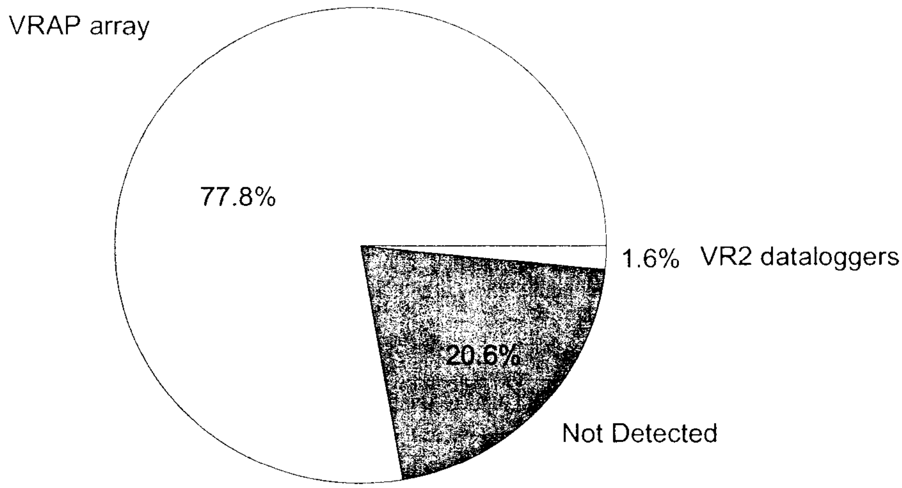
ID 14 2002


VR2 6 & 7
upstream
Site
VR2 5
VRAP
downstream
VR2 1,2,
3, & 4
12-Aug-02
26-Aug-02
09-Sep-02
23-Sep-02
07-Oct-02
21-Oct-02

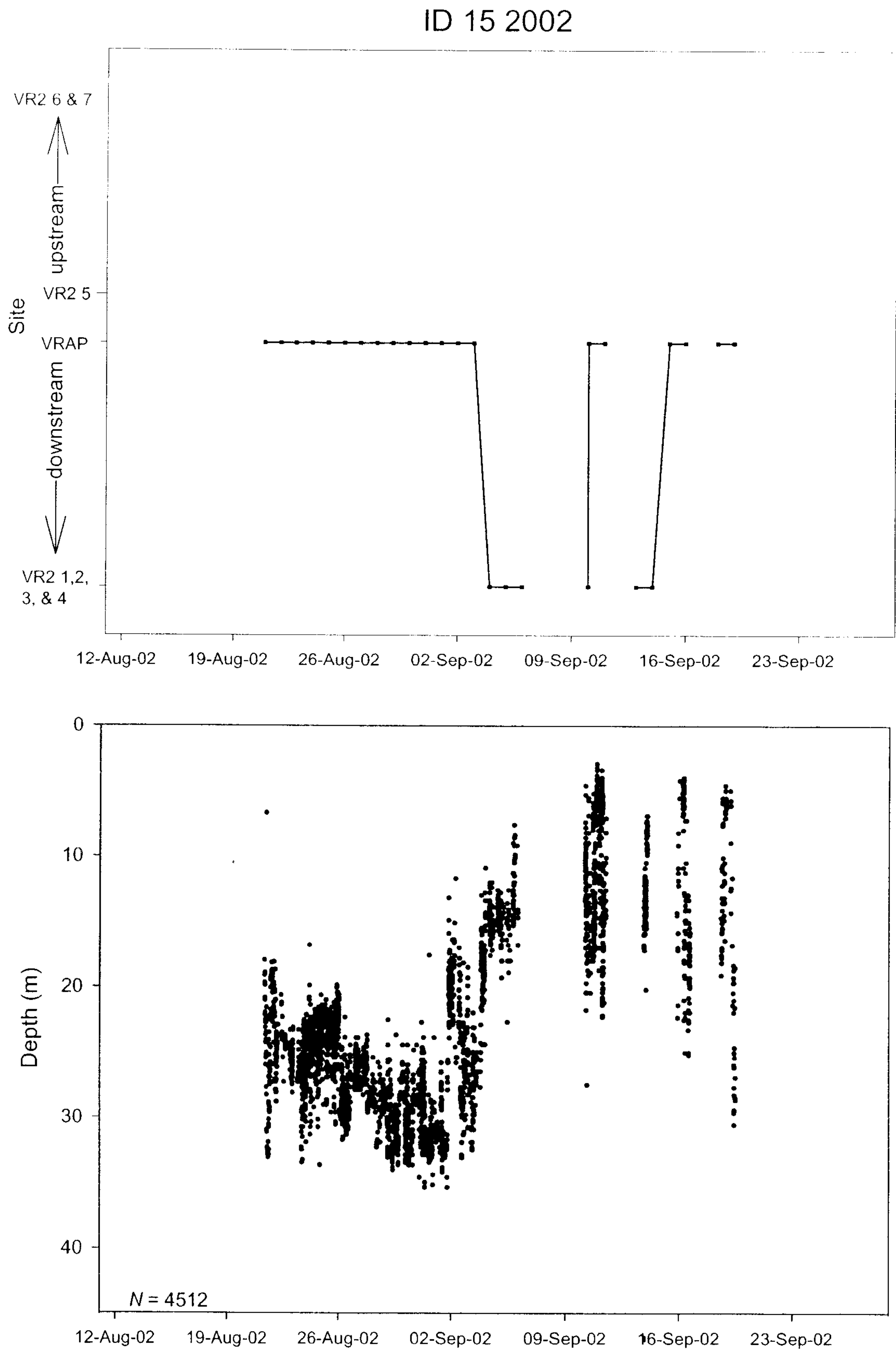

0
10
20
30
40
Depth (m)
N = 8620
12-Aug-02
26-Aug-02
09-Sep-02
23-Sep-02
07-Oct-02
21-Oct-02

Appendix F continued.

D 14 - Presence/Absence at USGS receiver locations
20 August 2002 to 21 October 2002

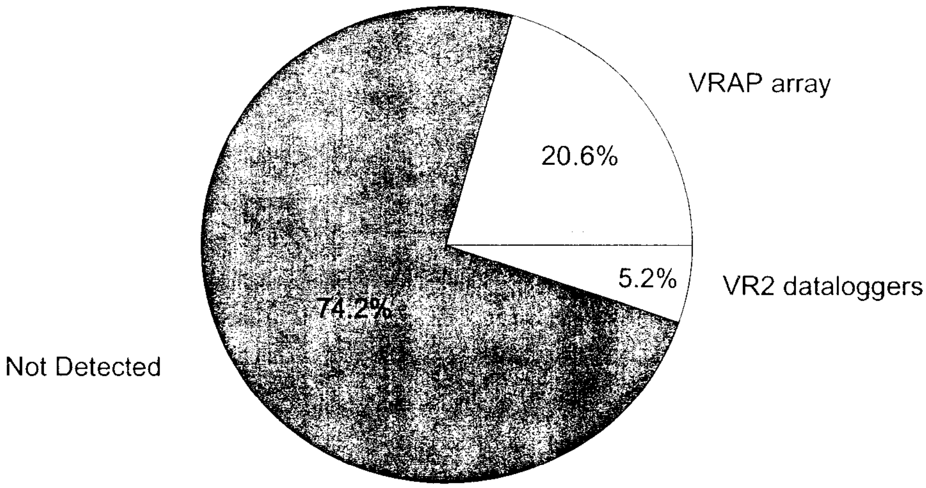


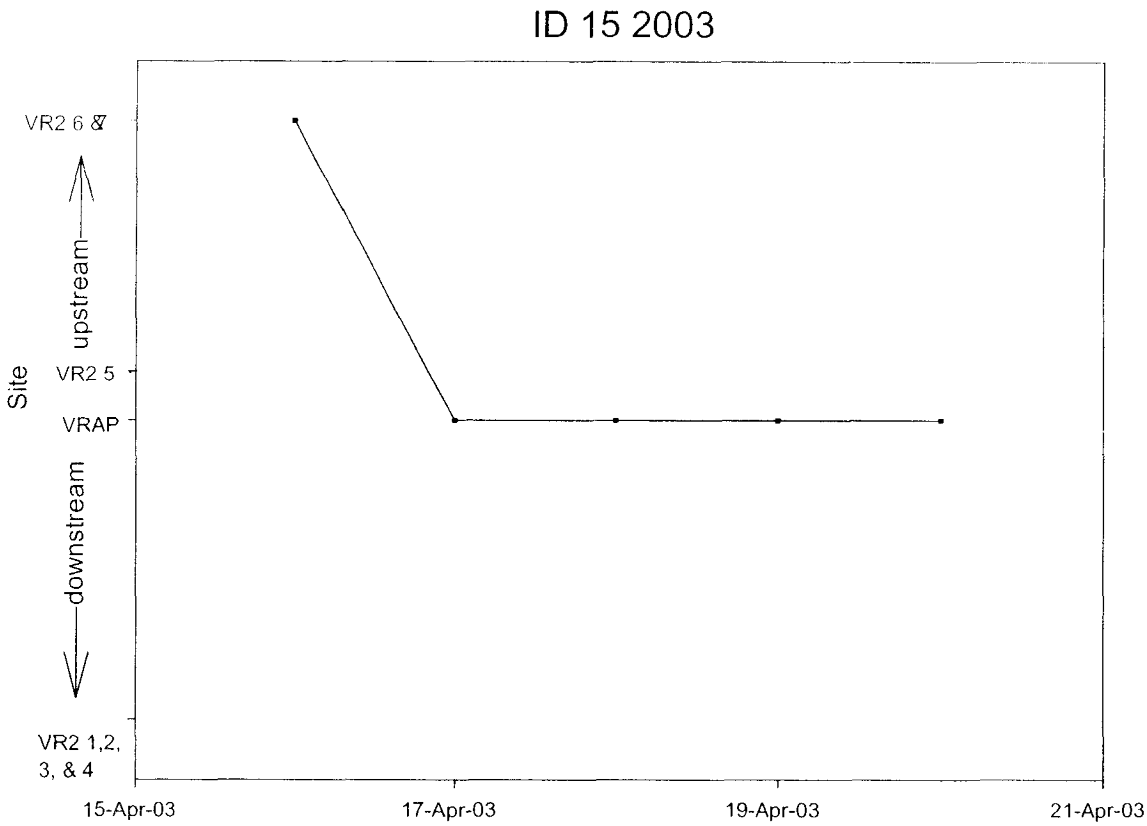
Appendix F continued.

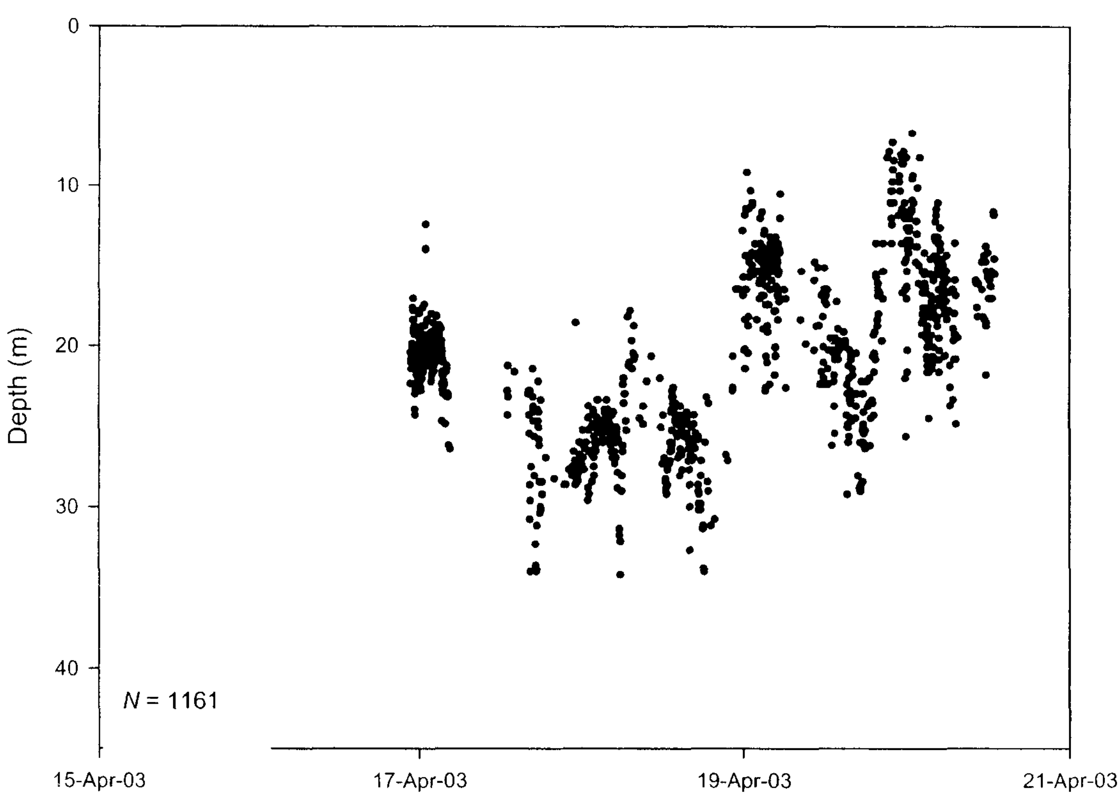


Appendix F continued.

D 15 - Presence/Absence at USGS receiver locations
21 August 2002 to 26 November 2002

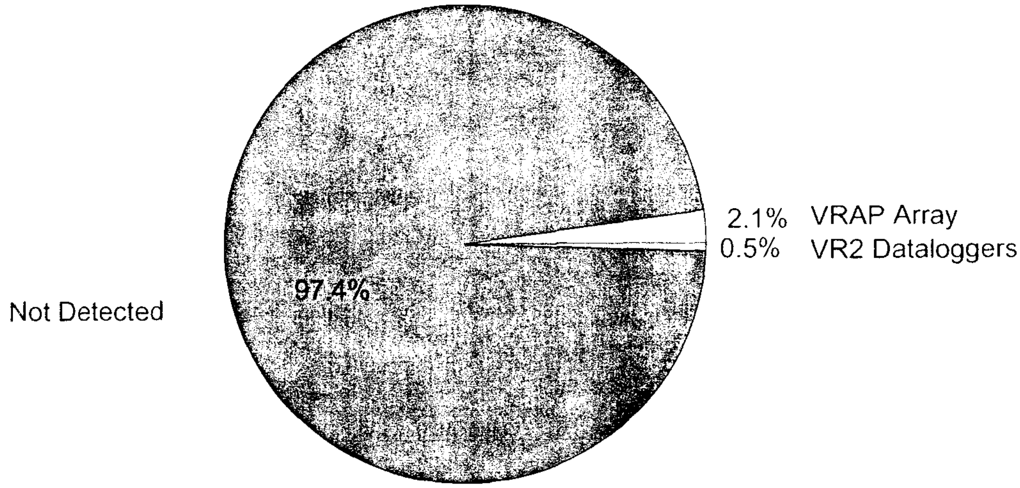



ID 15 2003
VR2 6 & 7
upstream
Site
VR2 5
VRAP
downstream
VR2 1,2, 3, & 4
15-Apr-03
17-Apr-03
19-Apr-03
21-Apr-03

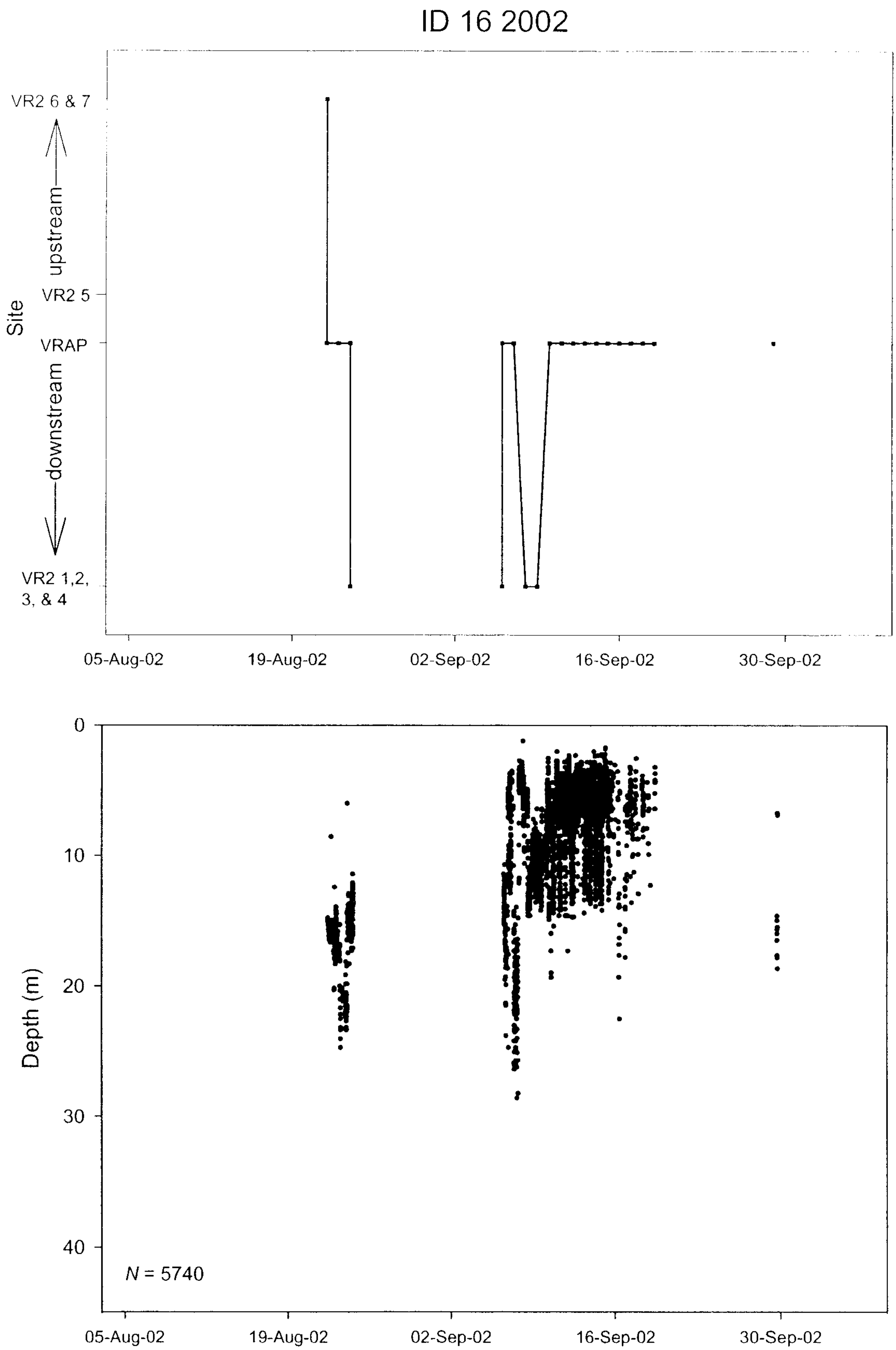

0
10
20
30
40
Depth (m)
N = 1161
15-Apr-03
17-Apr-03
19-Apr-03
21-Apr-03

Appendix F continued.

ID 15 - 2003 Presence/Absence at USGS receiver locations
8 April 2003 - 13 October 2003

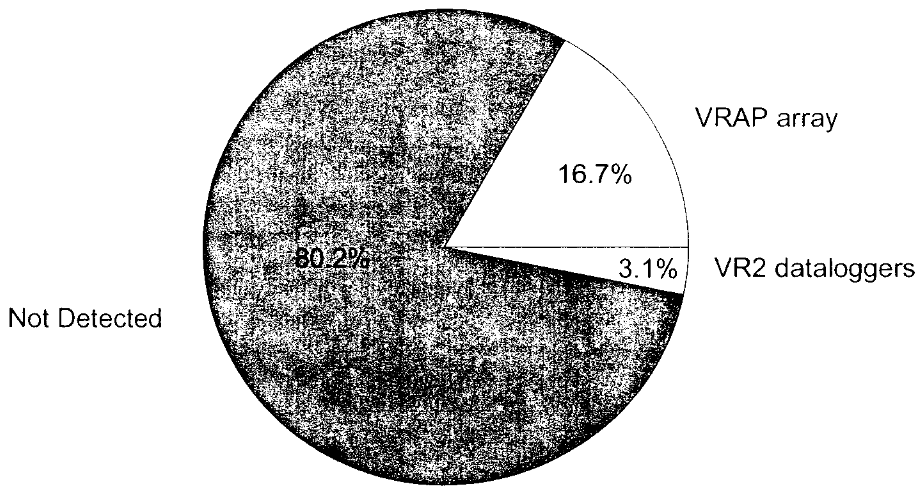


Appendix F continued.

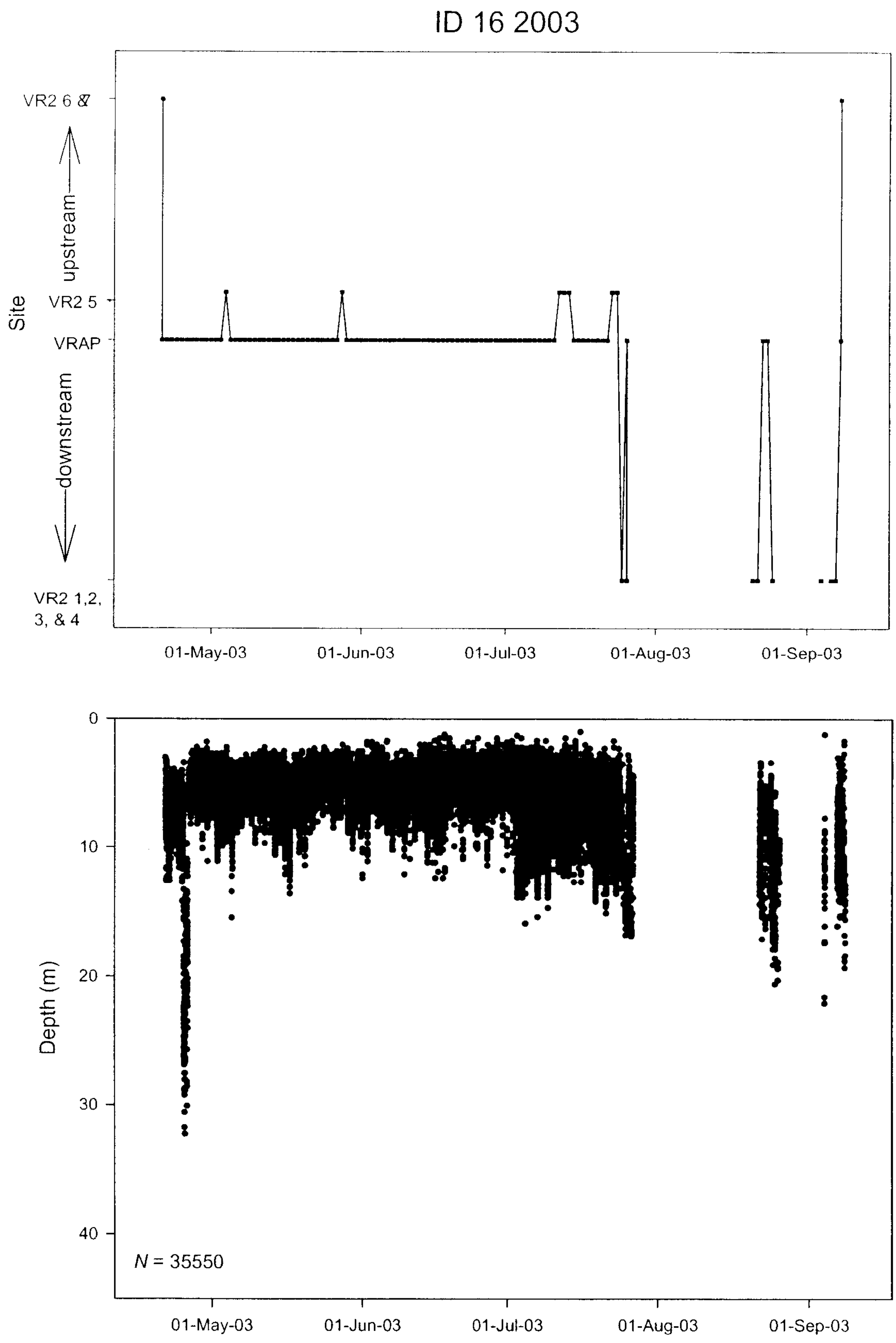


Appendix F continued.

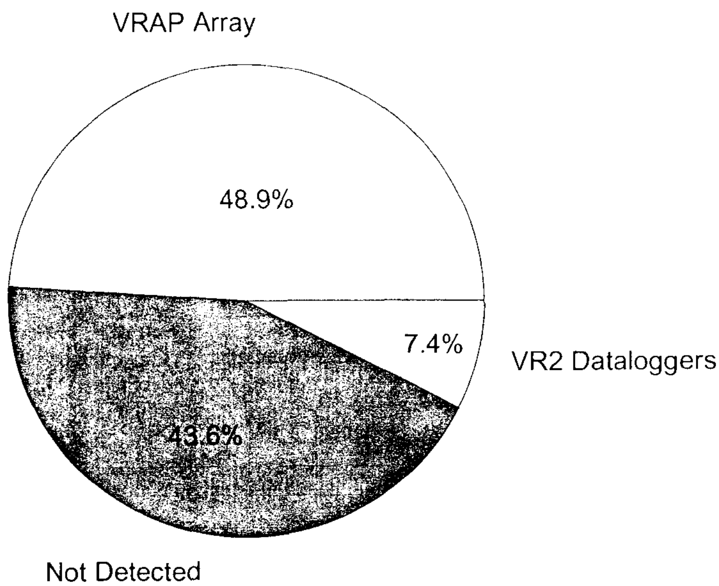
D 1 6 - Presence/Absence at USGS receiver locations
22 August 2002 to 26 November 2002



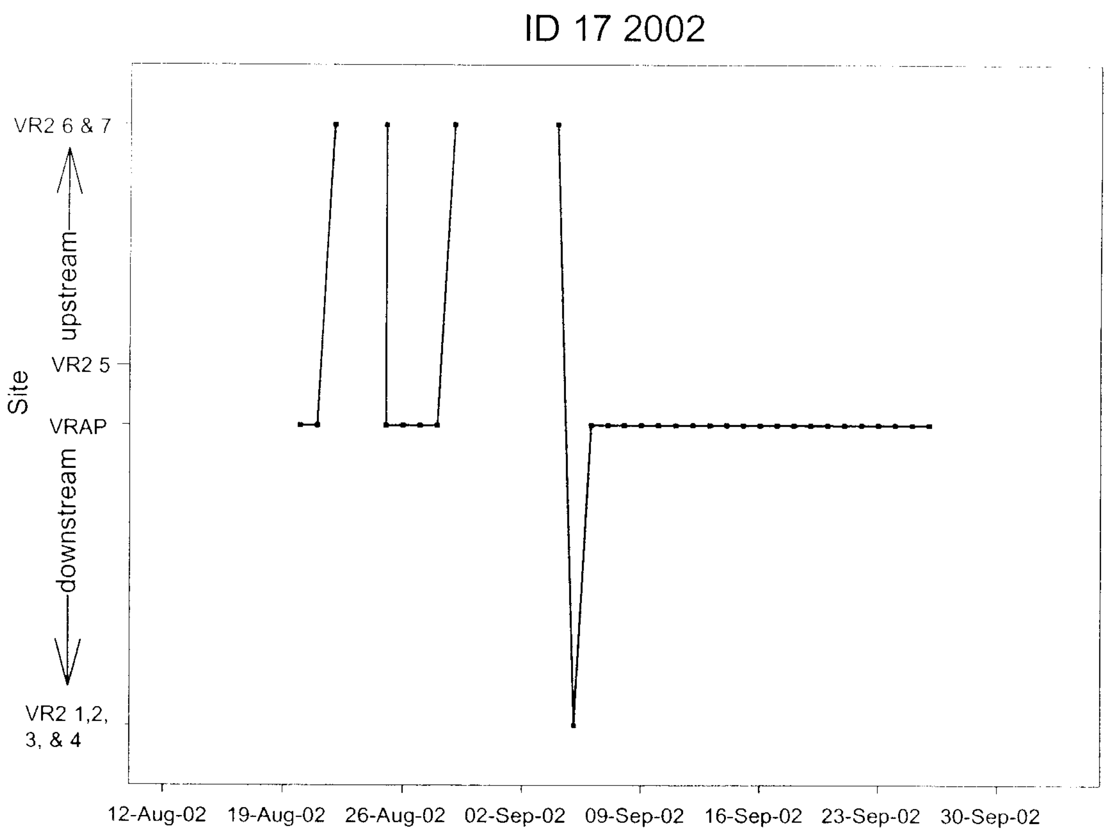
Appendix F continued.

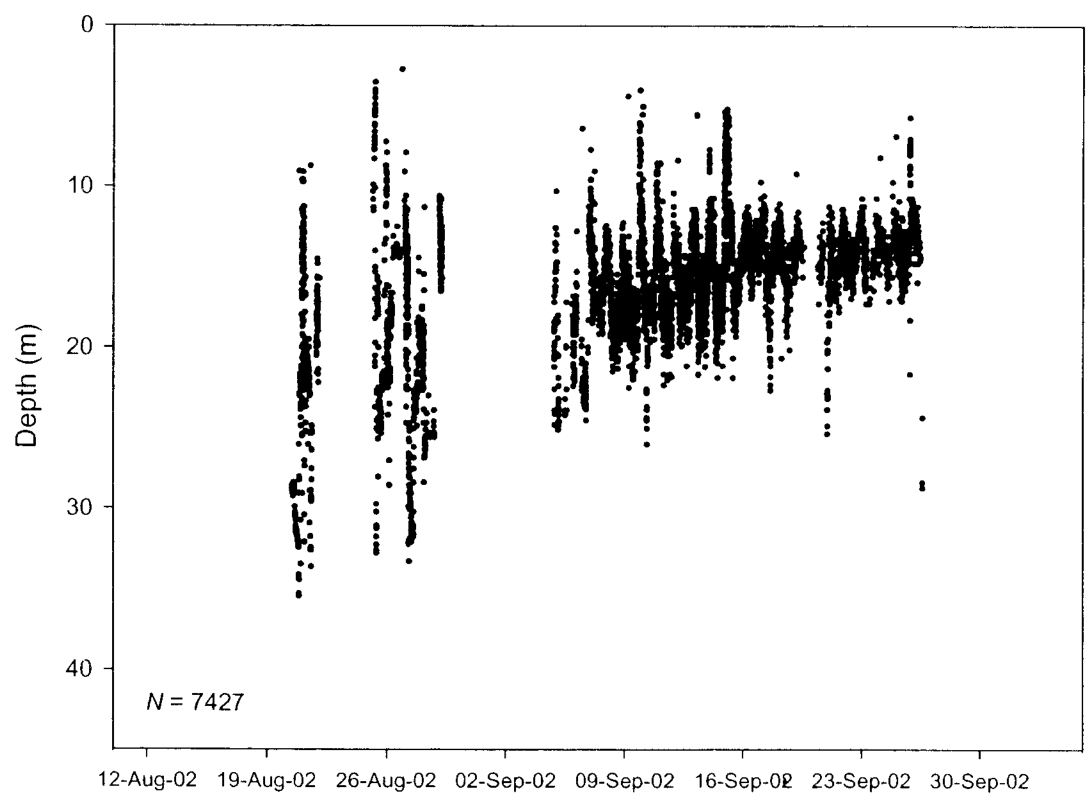


ID 16 - 2003 Presence/Absence at USGS receiver locations
8 April 2003 - 13 October 2003



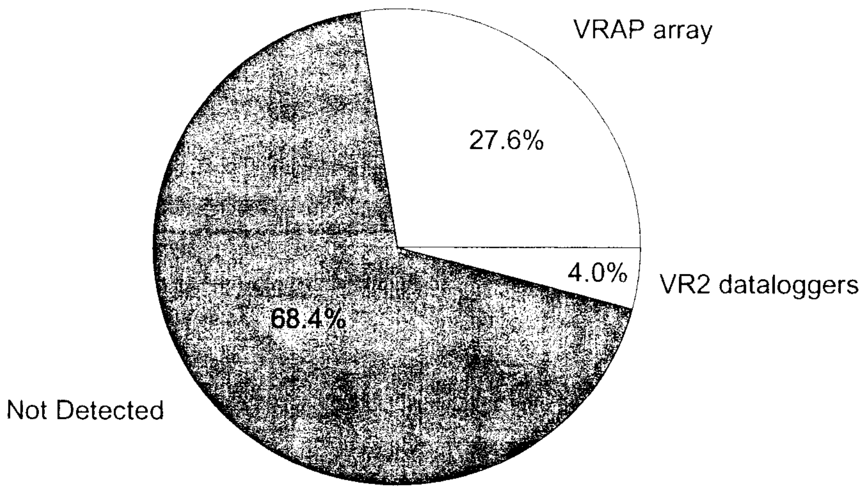
Appendix F continued.





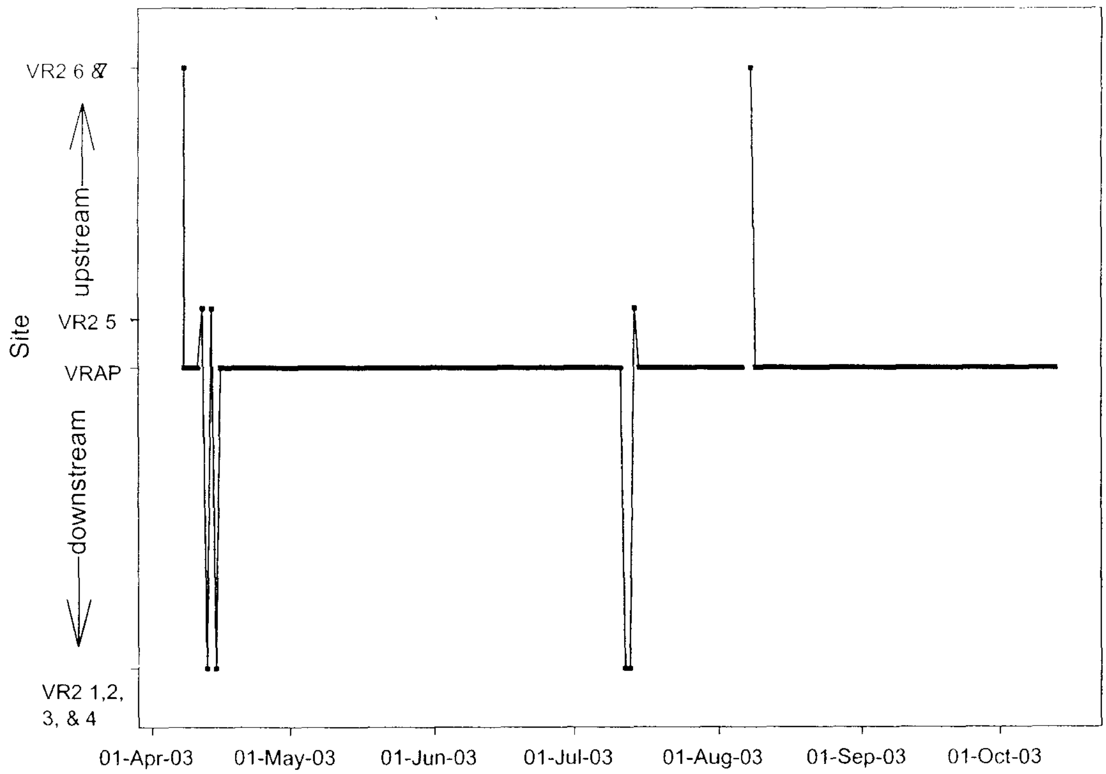
Appendix F continued.

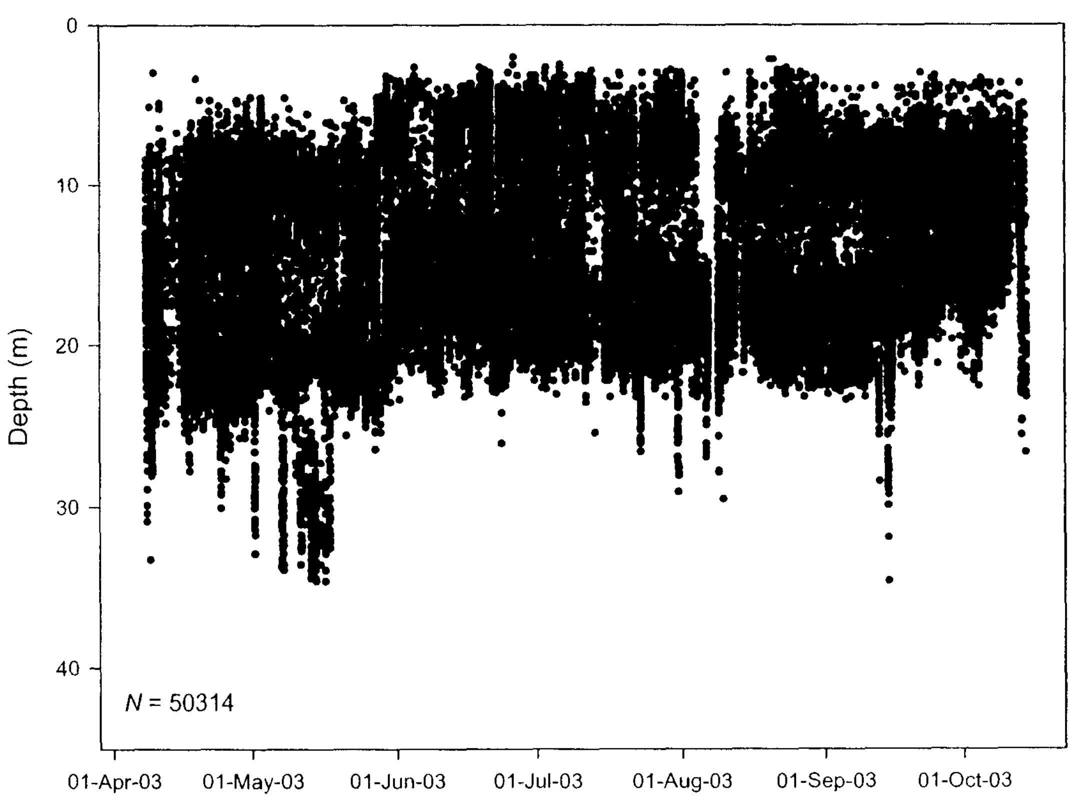
D 17 - Presence/Absence at USGS receiver locations
20 August 2002 to 26 November 2002



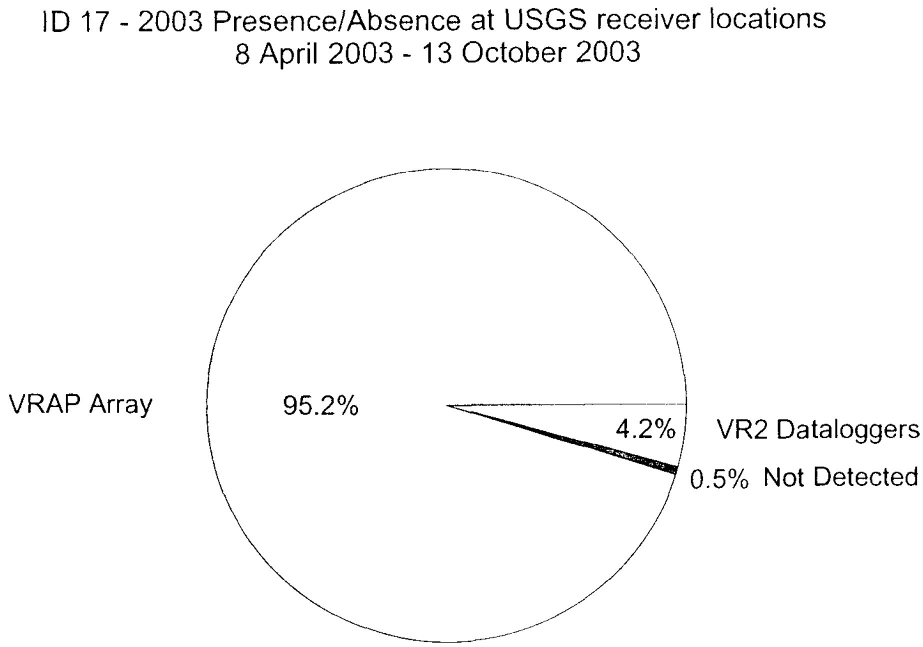
Appendix F continued.

ID 17 2003

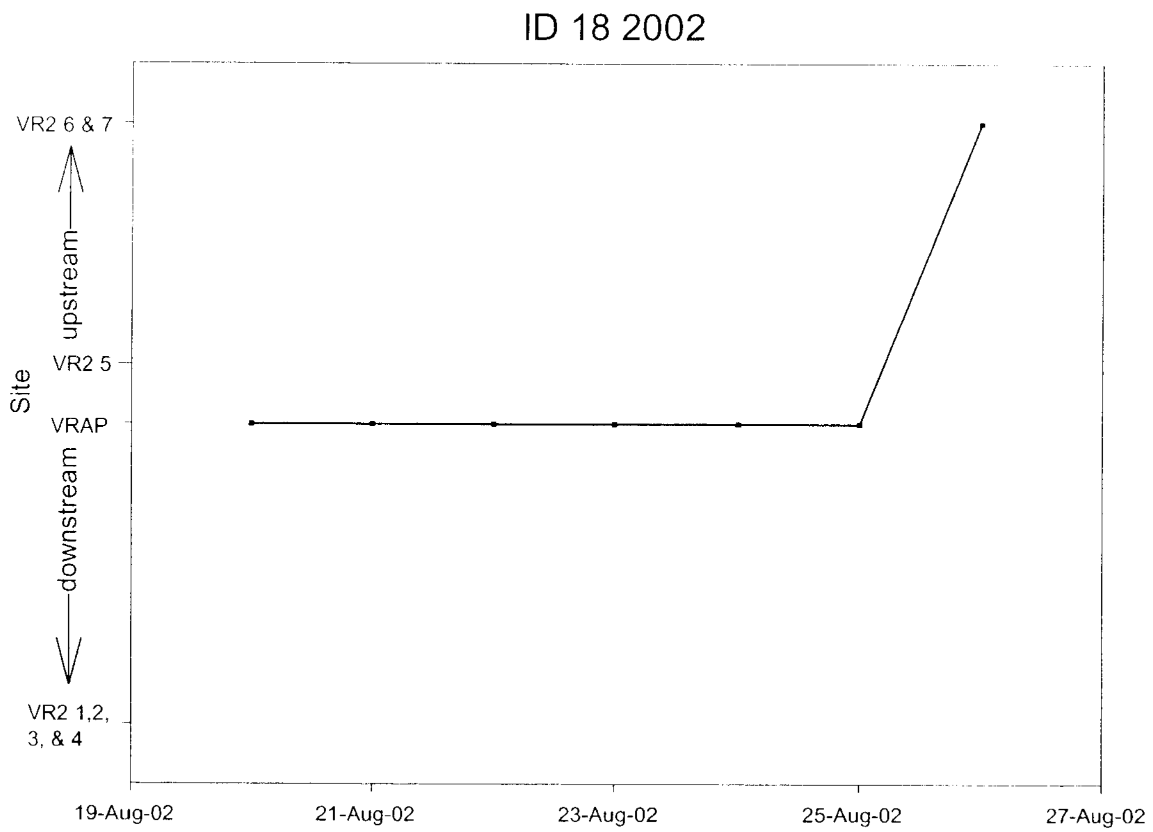


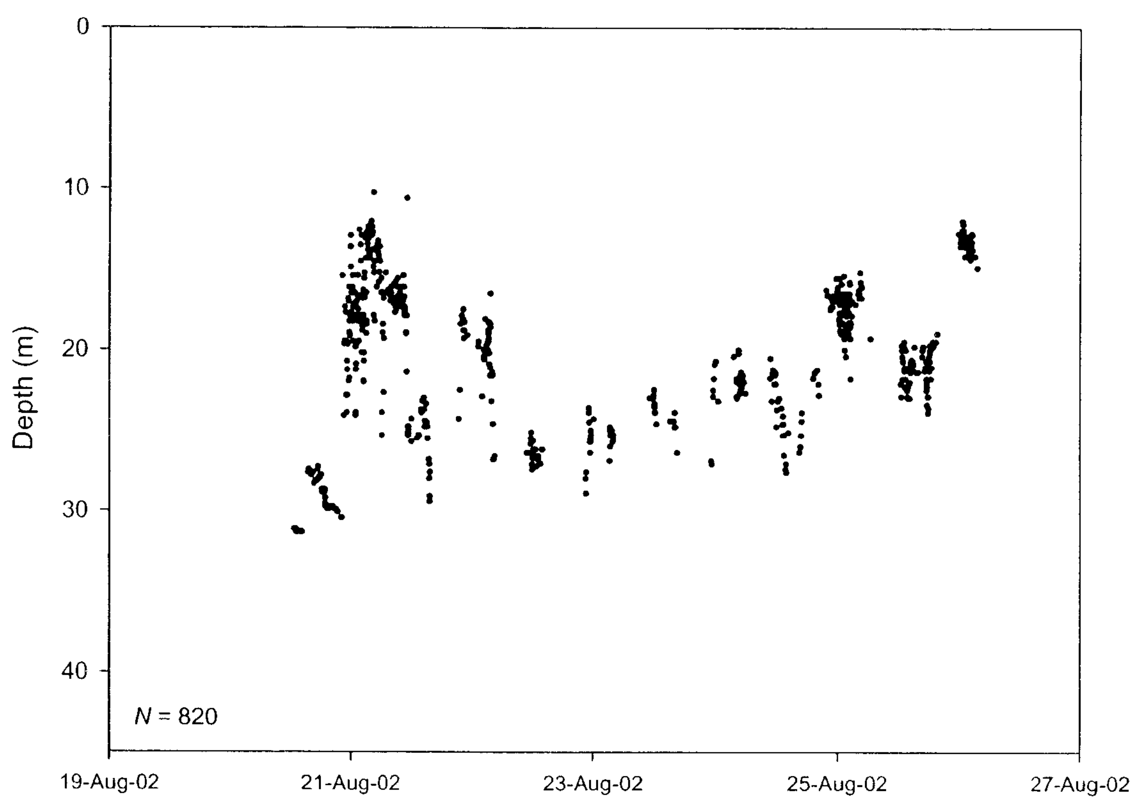


Appendix F continued.



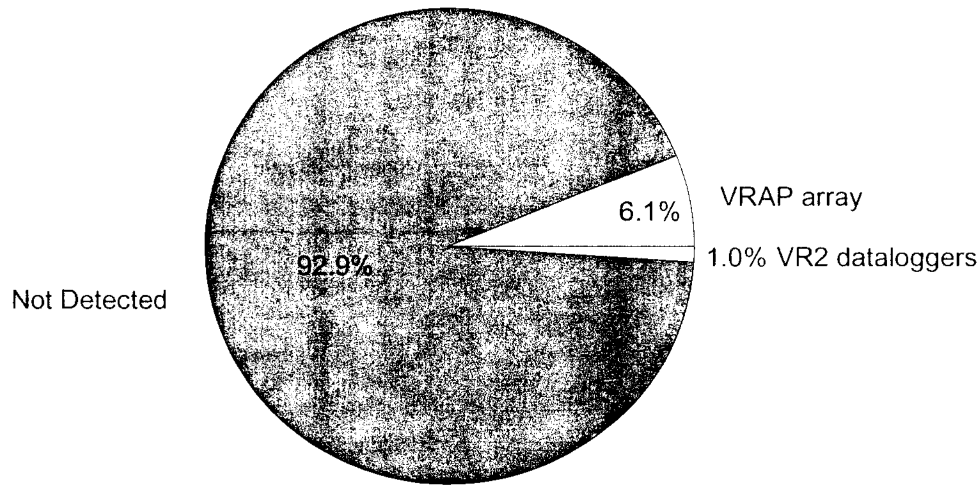
Appendix F continued.



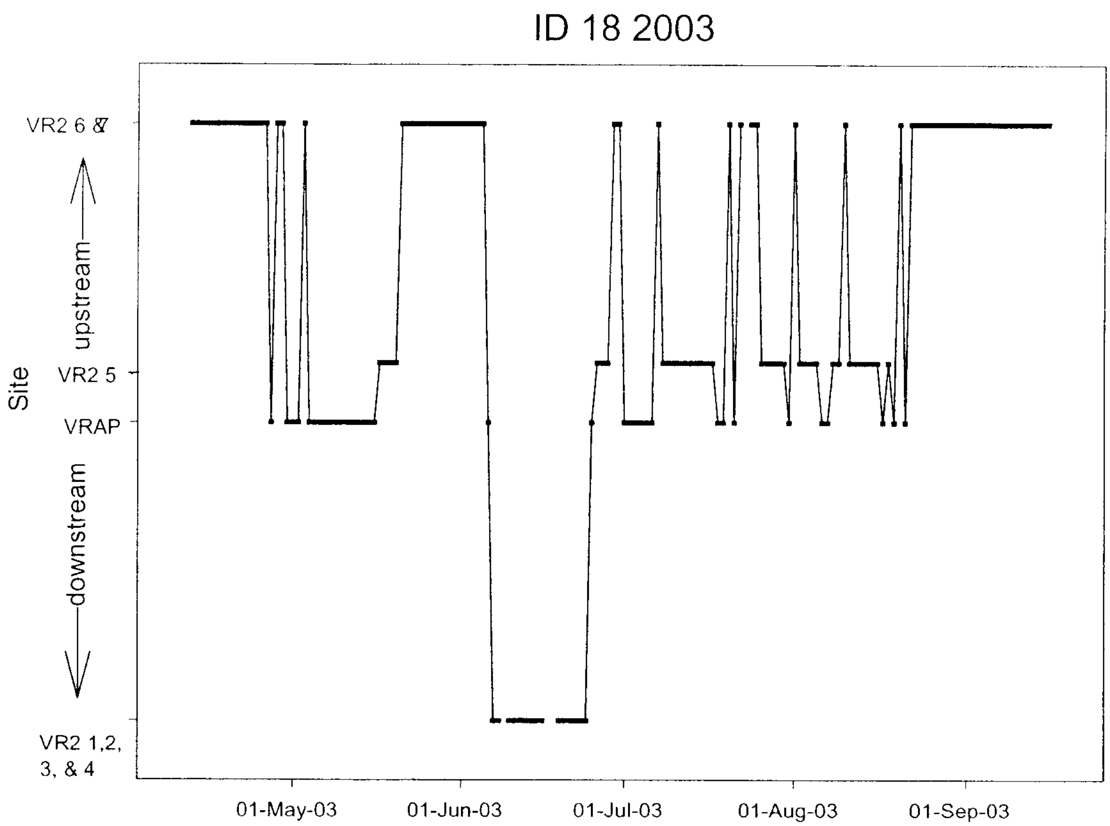


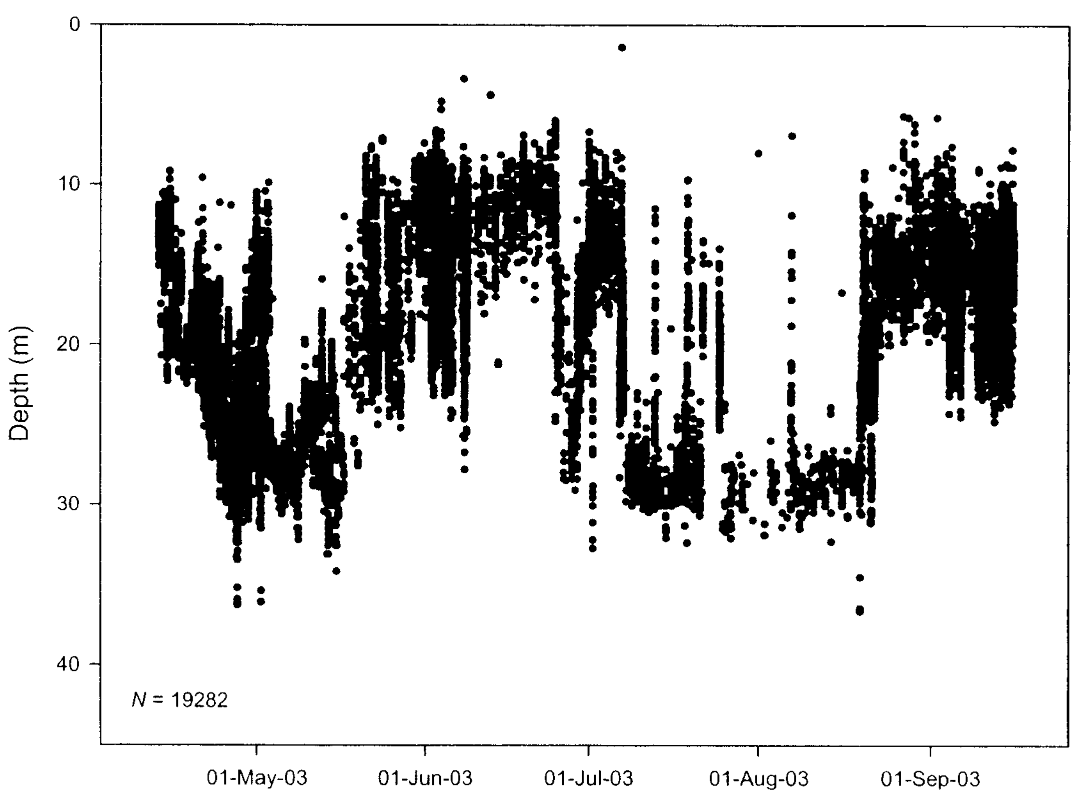
Appendix F continued.

D 1 8 - Presence/Absence at USGS receiver locations
20 August 2002 to 26 November 2002

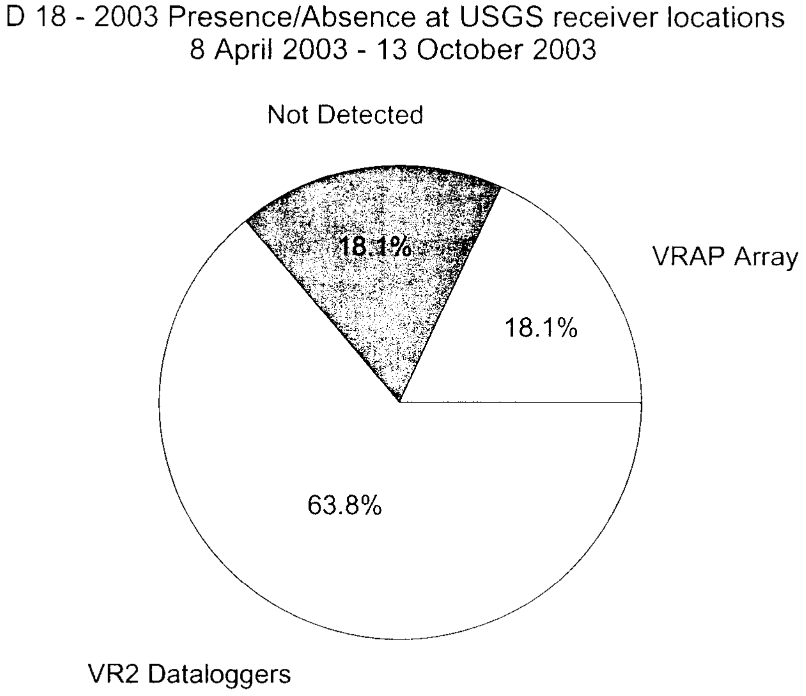


Appendix F continued.

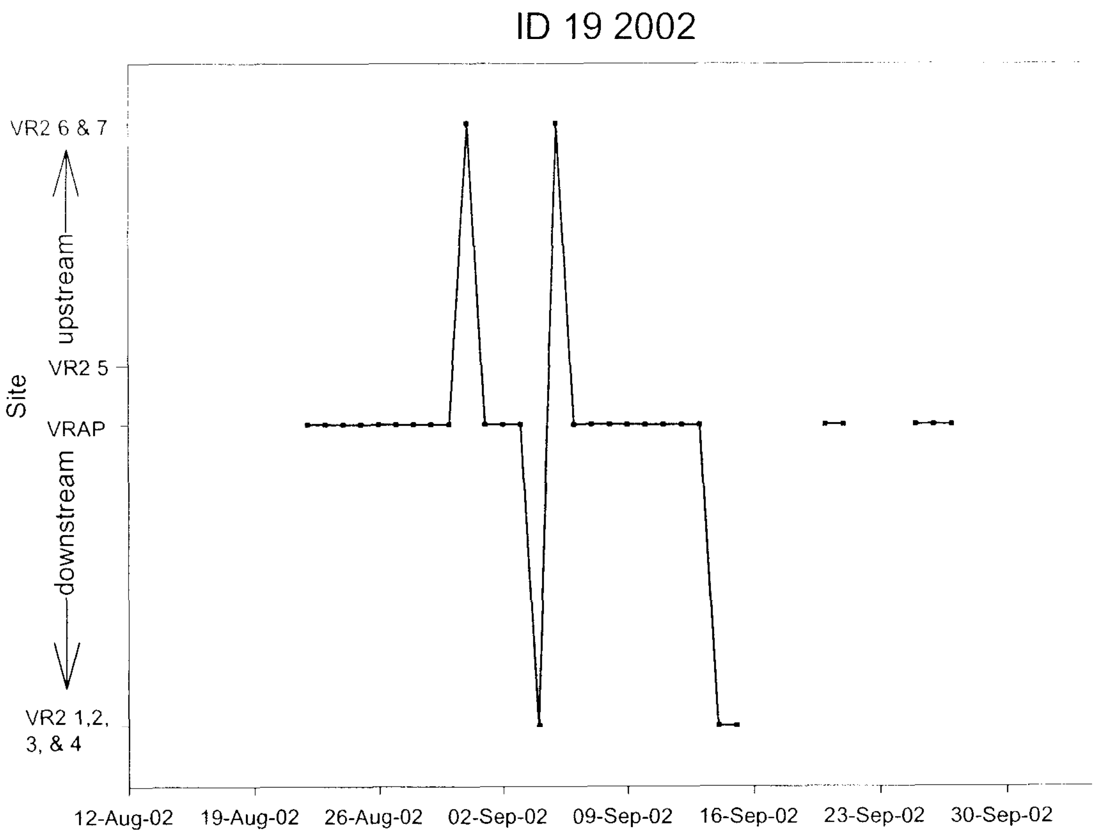


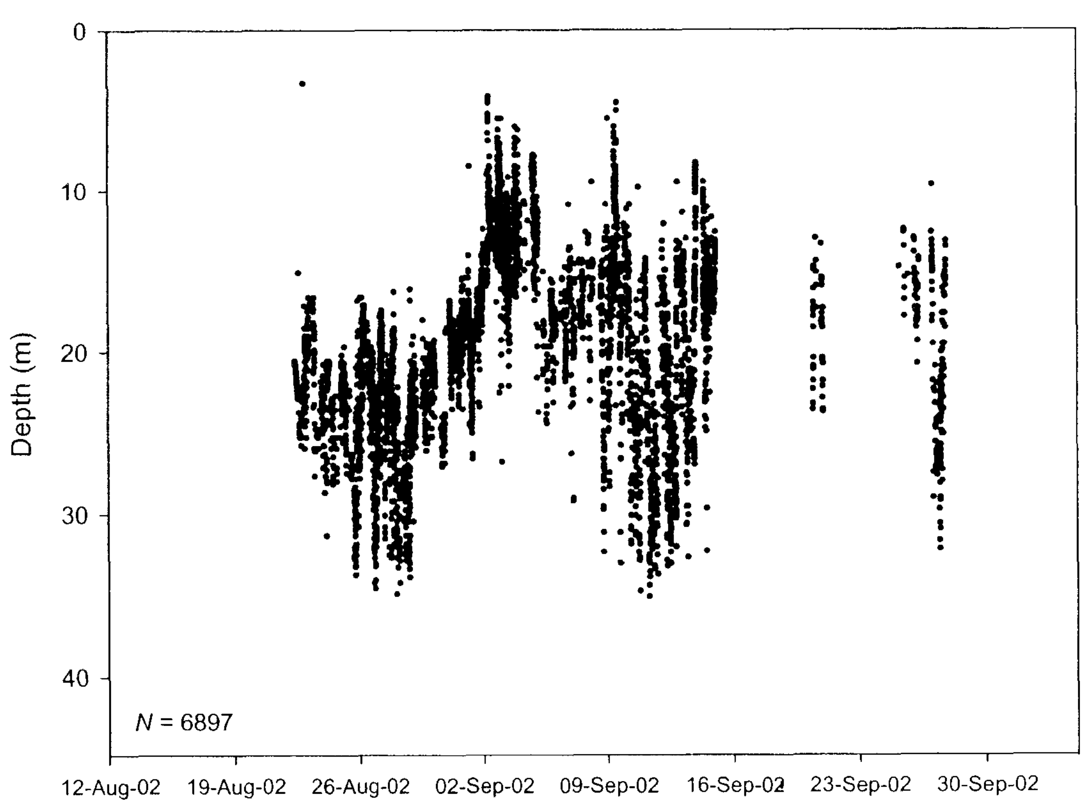


Appendix F continued.



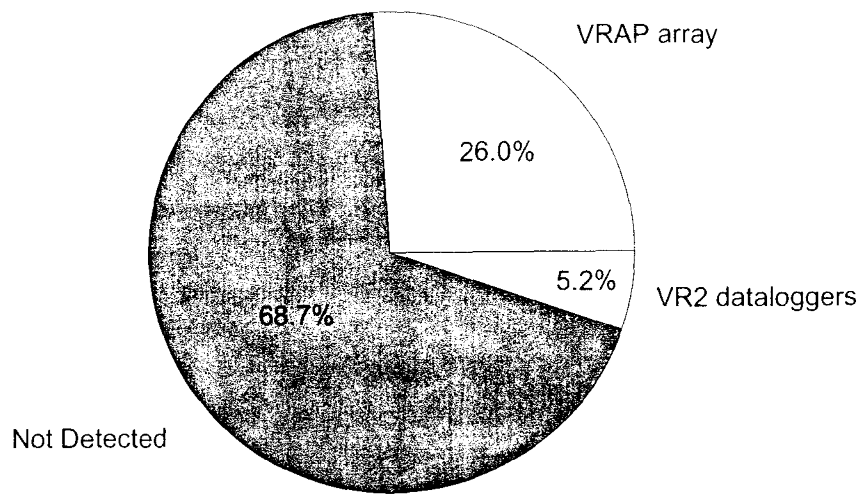
Appendix F continued.



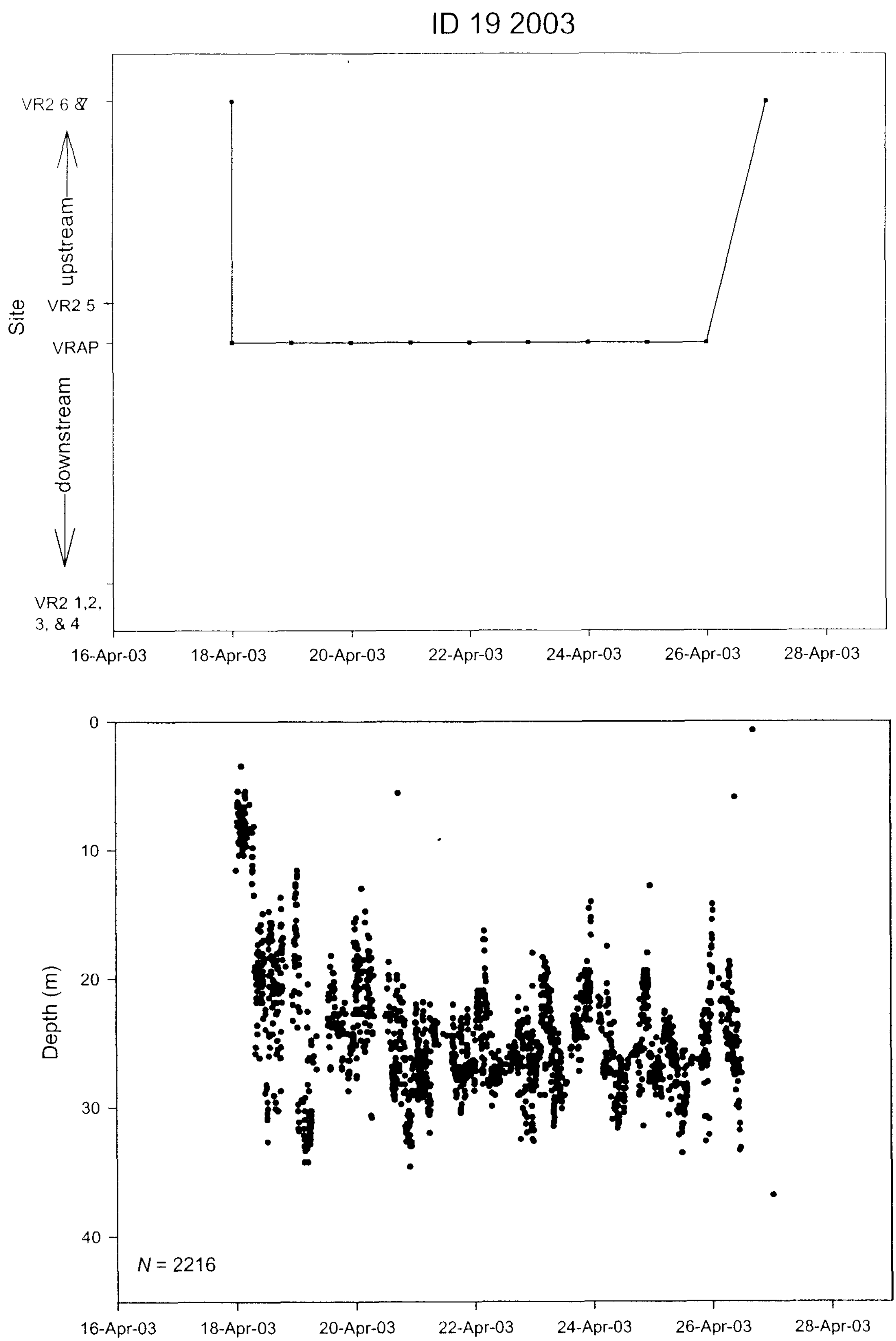


Appendix F continued.

D 19 - Presence/Absence at USGS receiver locations
22 August 2002 to 26 November 2002

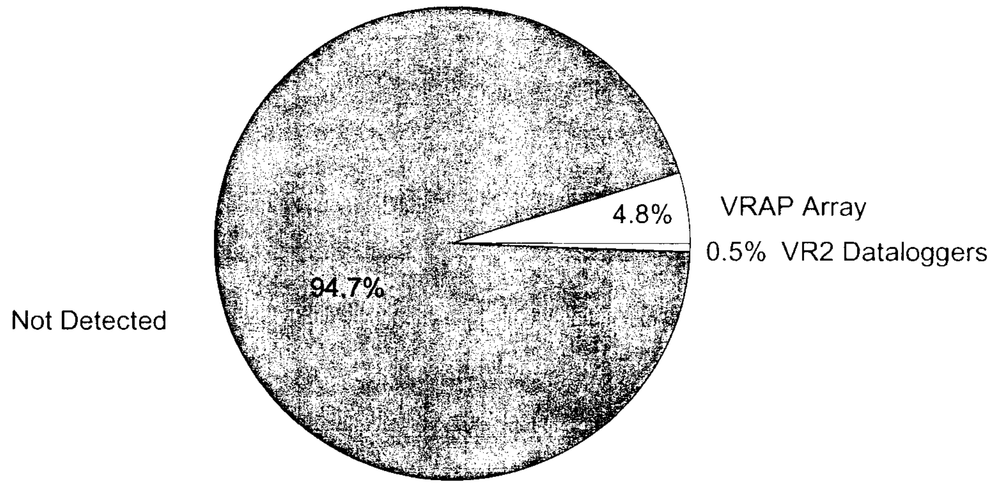


Appendix F continued.

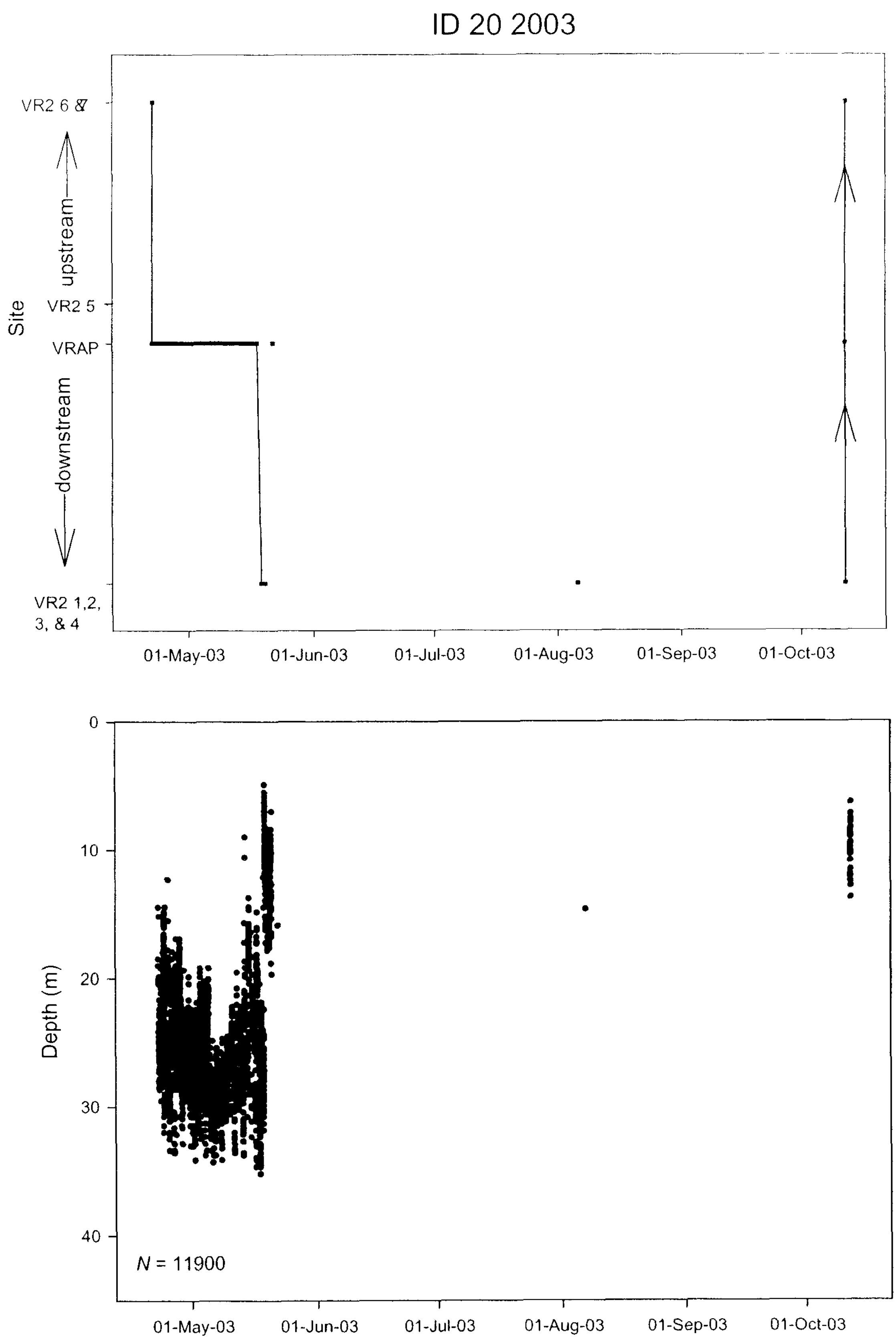


Appendix F continued.

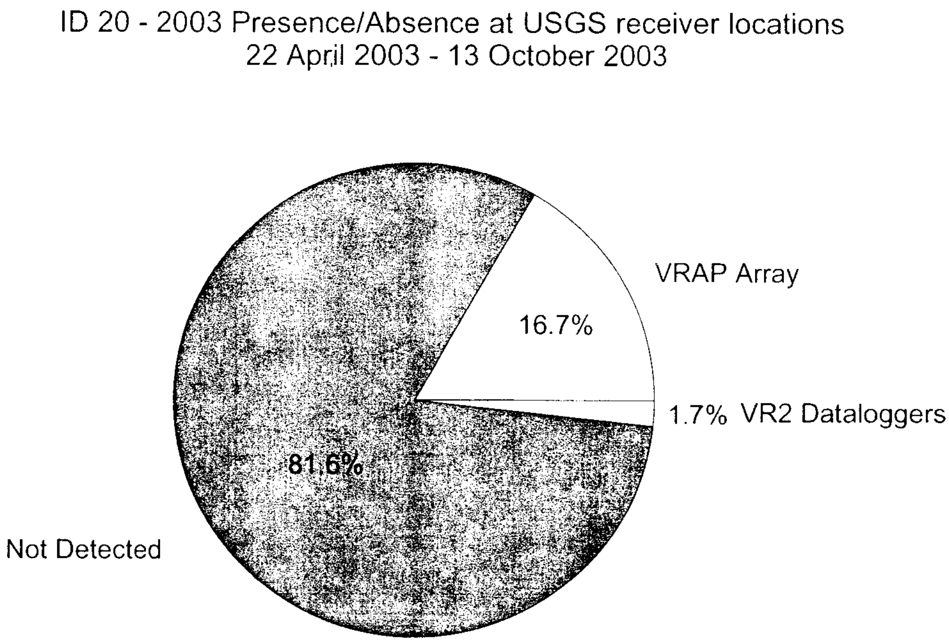
D 19 - 2003 Pr esence/Absence at USGS receiver locations
8 April 2003 - 13 October 2003



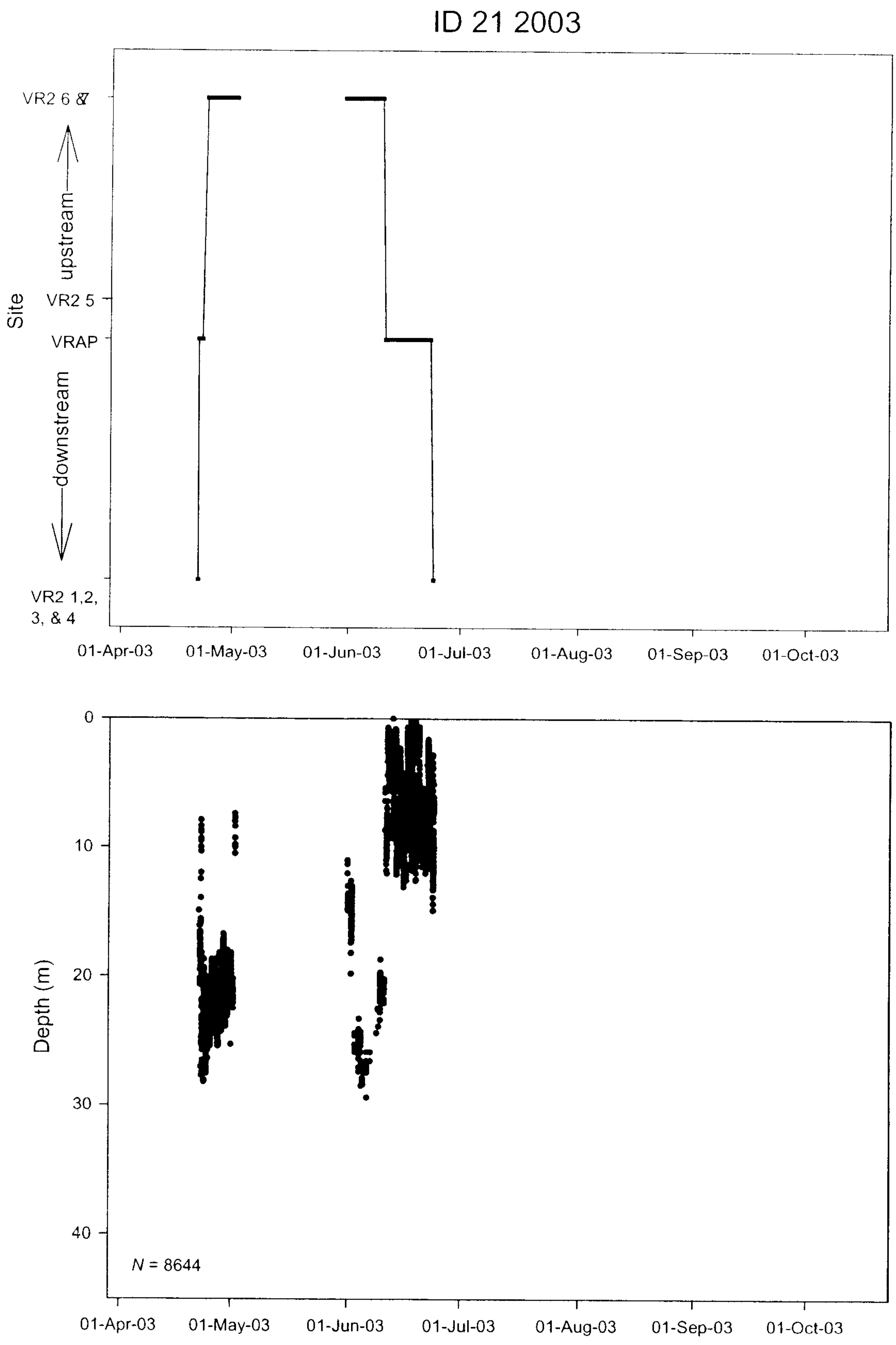
Appendix F continued.



Appendix F continued.

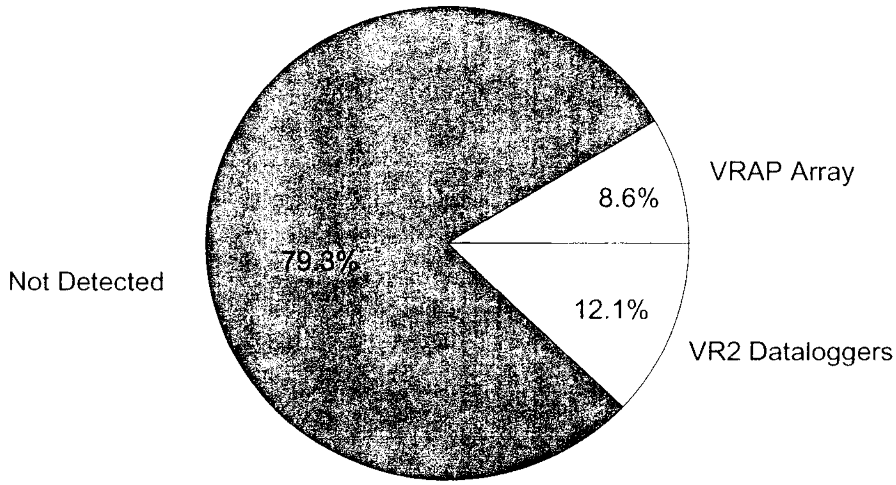


Appendix F continued.

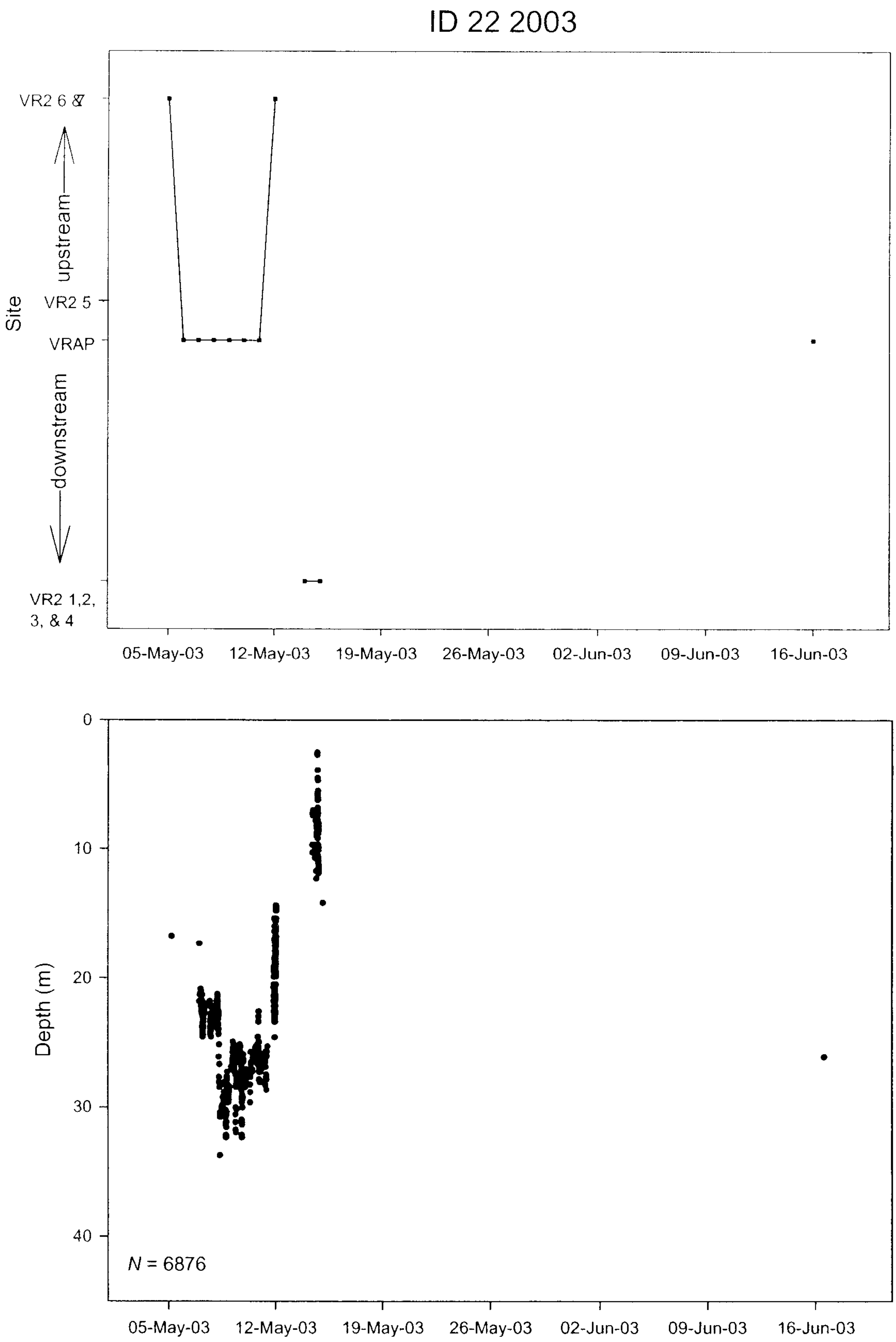


Appendix F continued.

ID 21 - 2003 Presence/Absence at USGS receiver locations
22 April 2003 - 13 October 2003

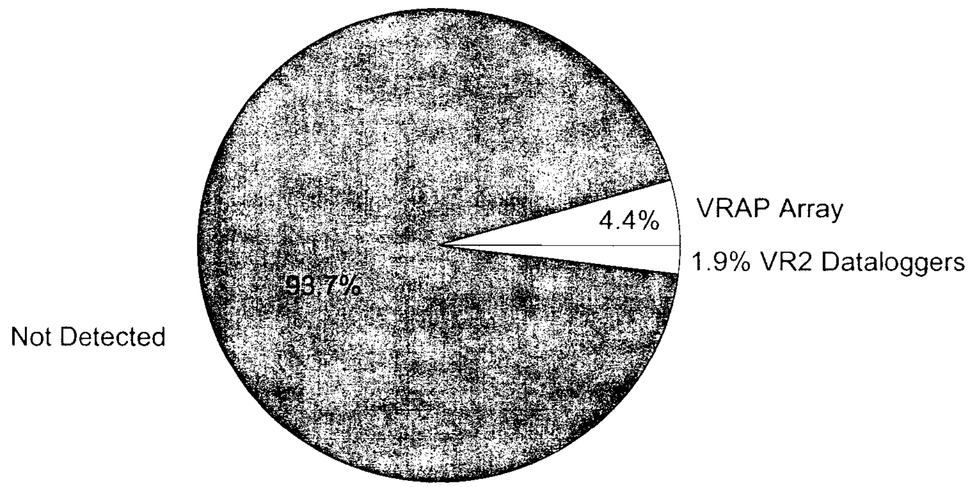


Appendix F continued.



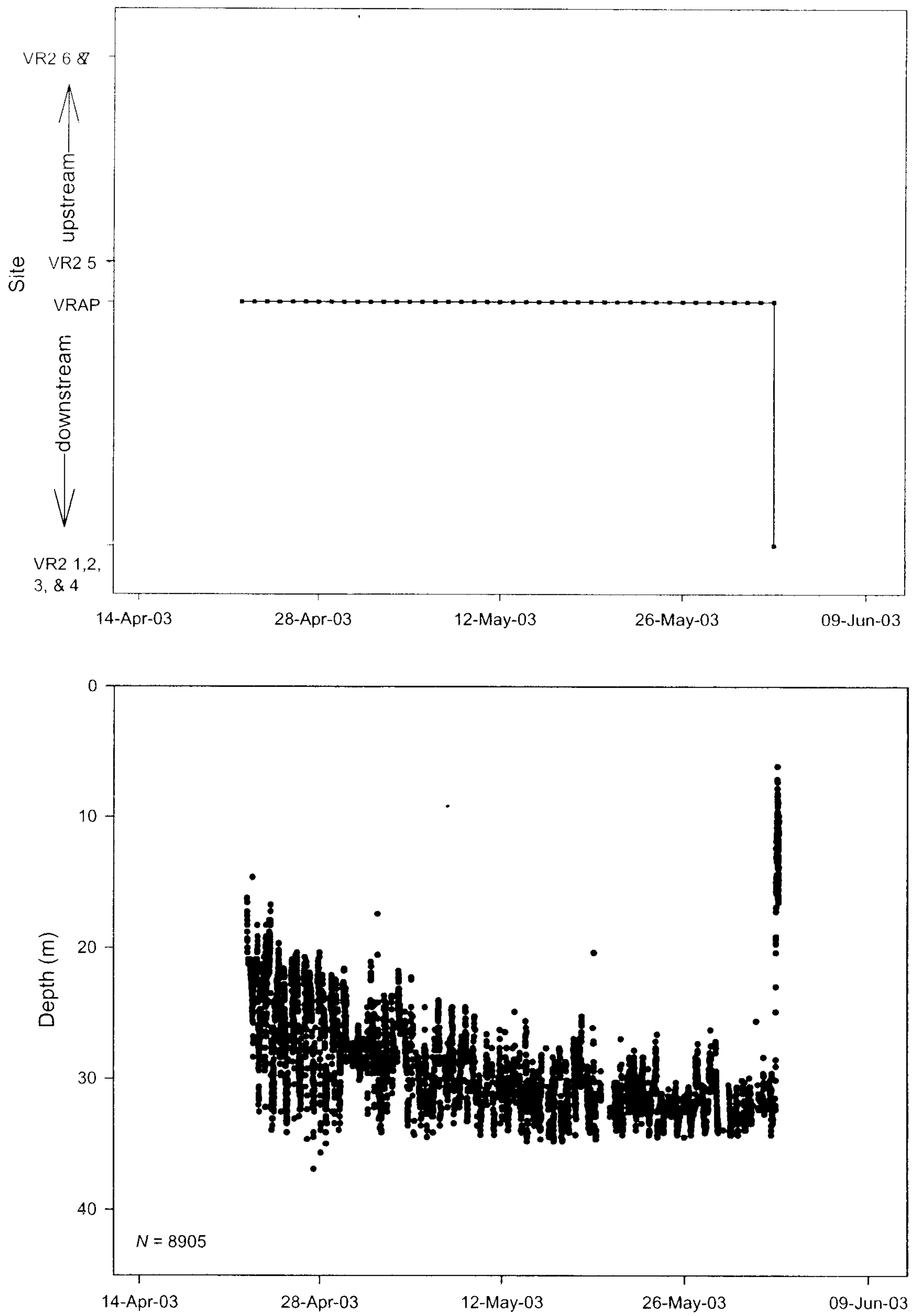
Appendix F continued.

ID 22 - 2003 Presence/Absence at USGS receiver locations
6 May 2003 - 13 May 2003

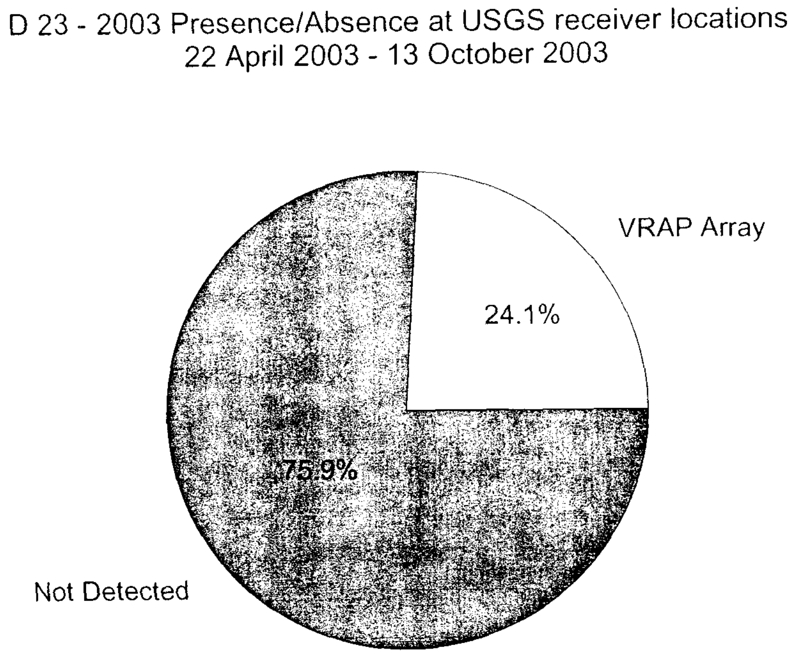


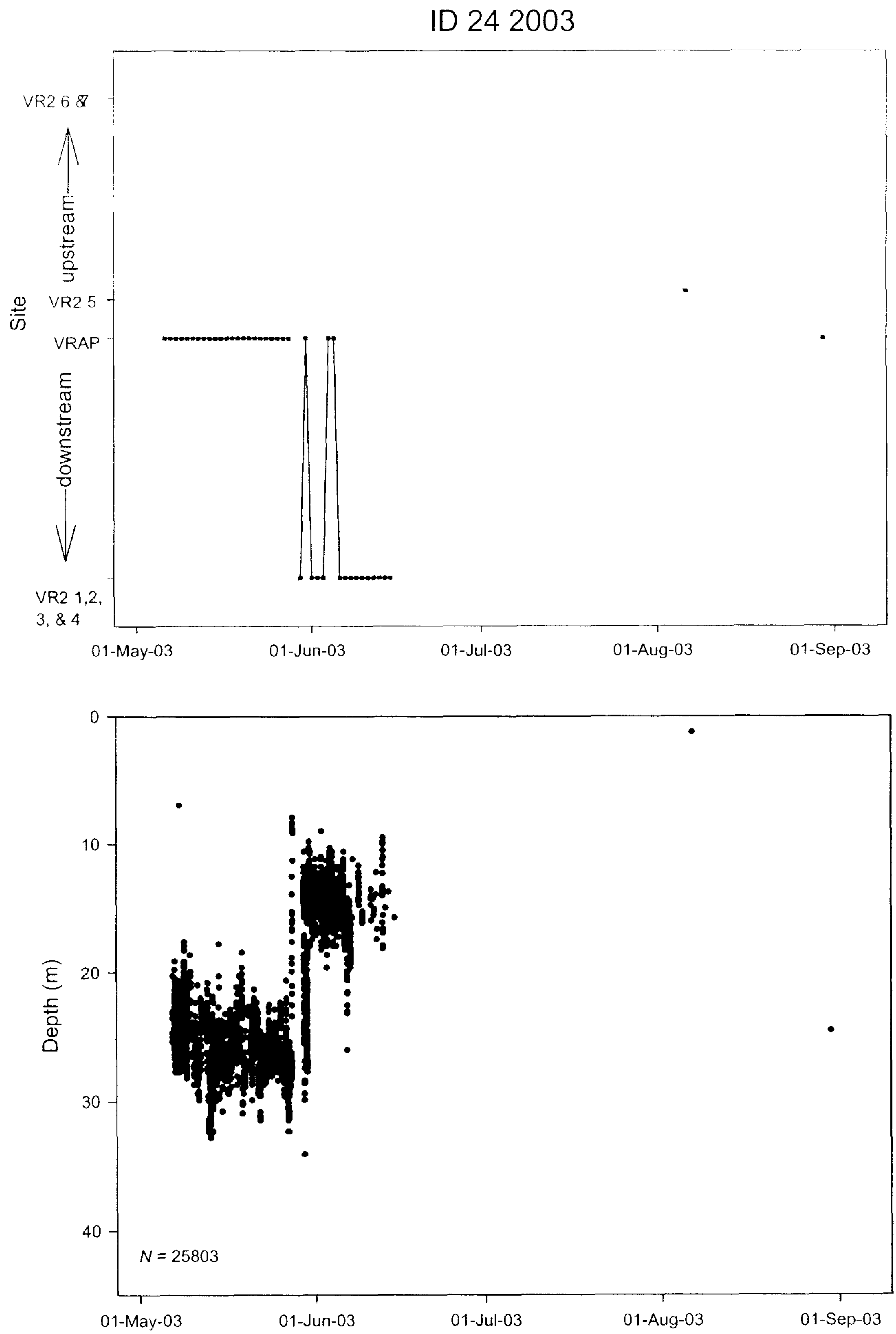
Appendix F continued.

ID 23 2003

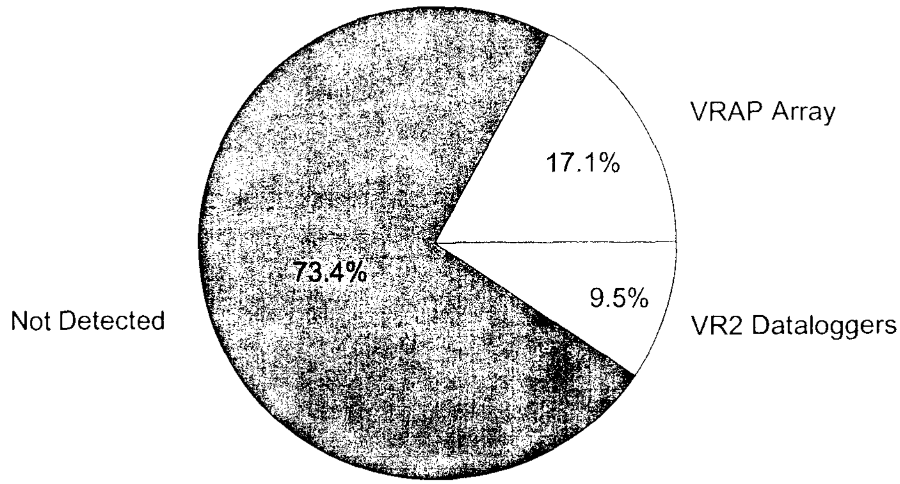


Appendix F continued.

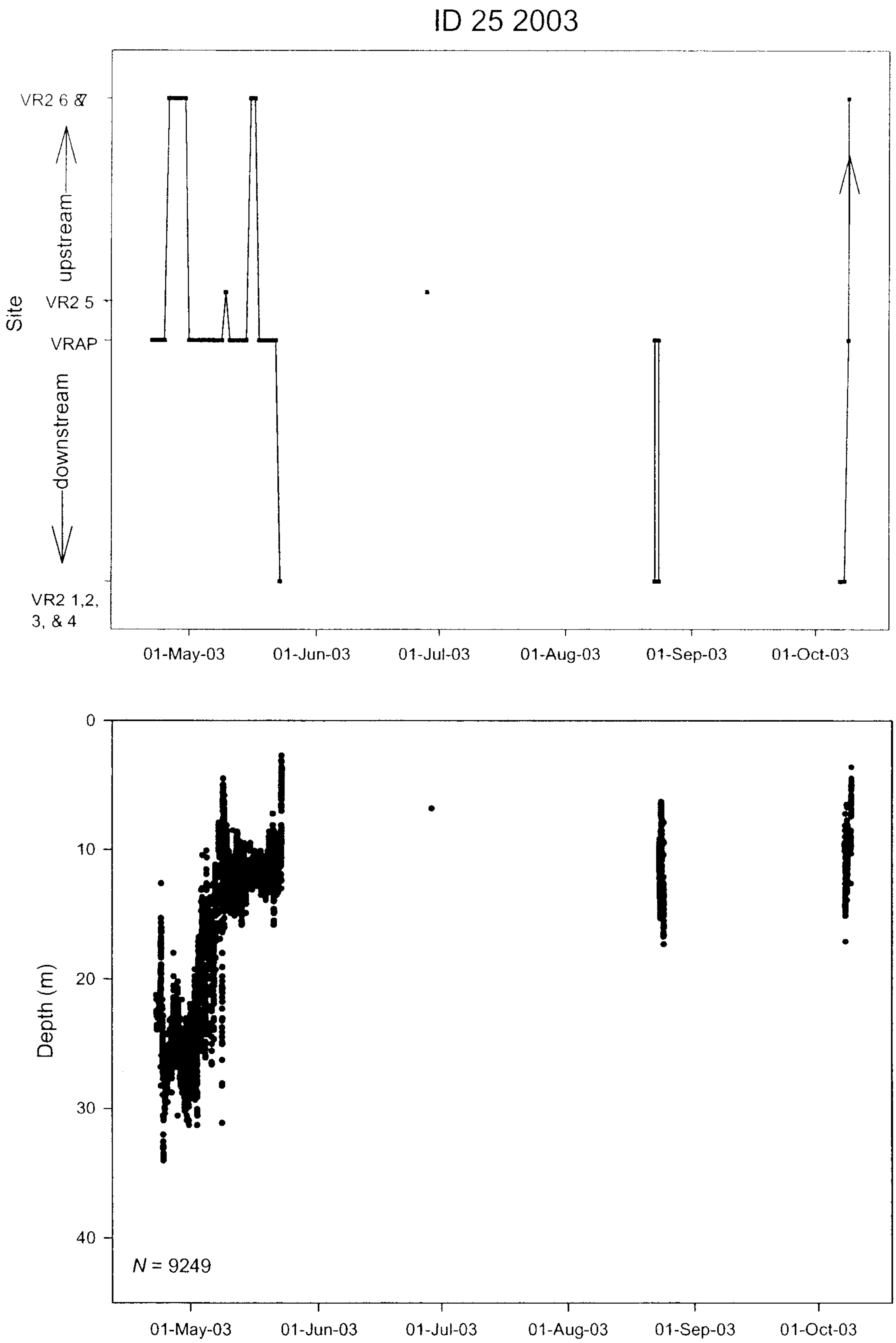



ID 24 2003
Site
VR2 6 & 7
upstream
VR2 5
VRAP
downstream
VR2 1,2, 3, & 4
01-May-03
01-Jun-03
01-Jul-03
01-Aug-03
01-Sep-03
Depth (m)
0
10
20
30
40
N = 25803
01-May-03
01-Jun-03
01-Jul-03
01-Aug-03
01-Sep-03

ID 24 - 2003 Presence/Absence at USGS receiver locations
6 May 2003 - 13 October 2003

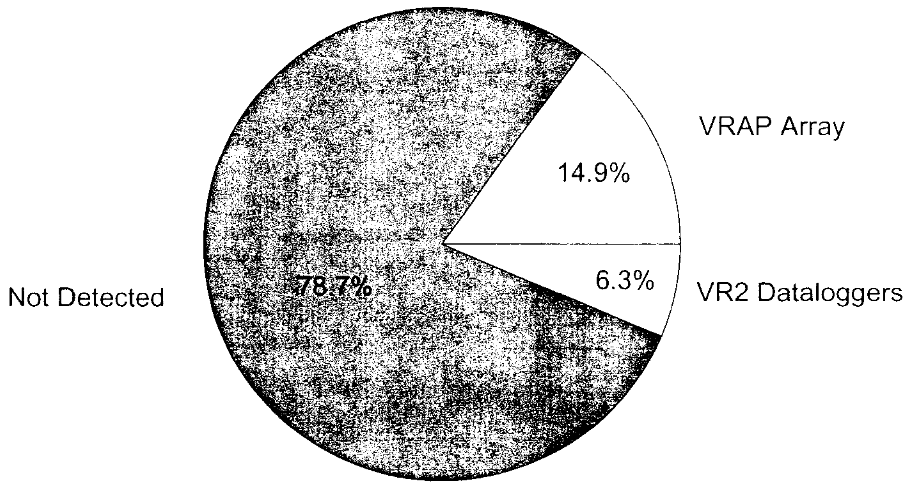


Appendix F continued.

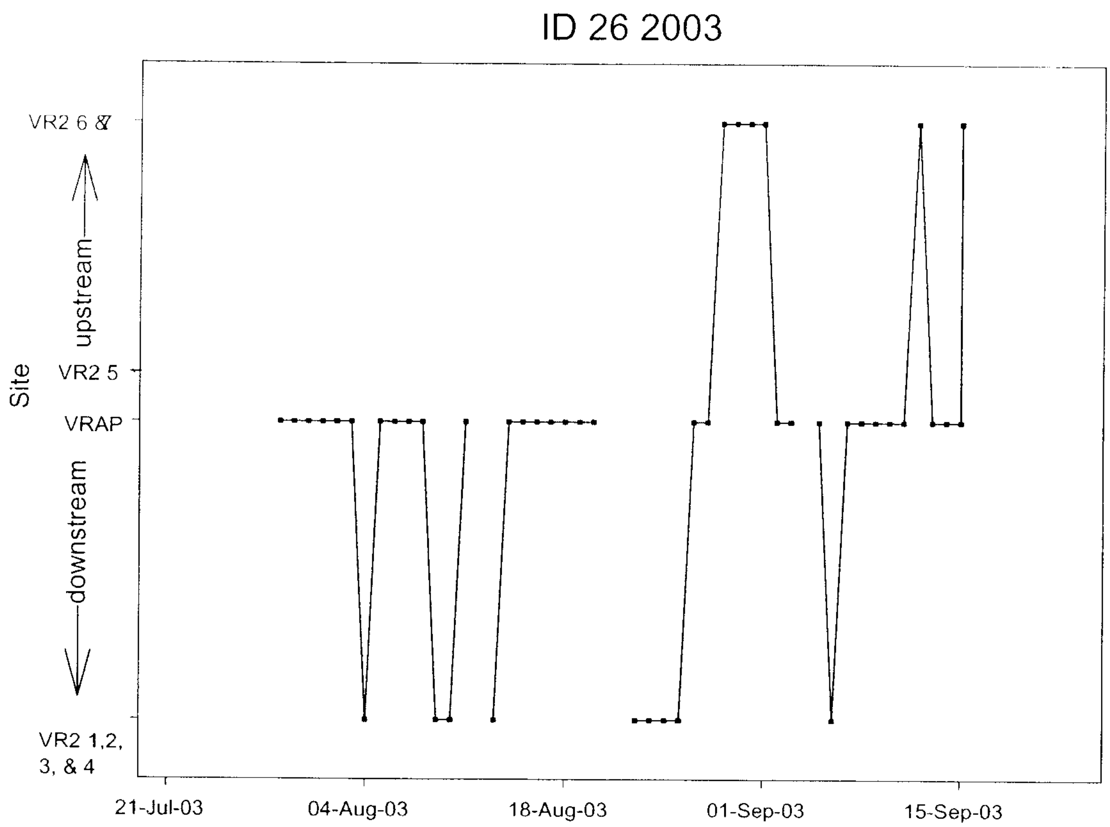


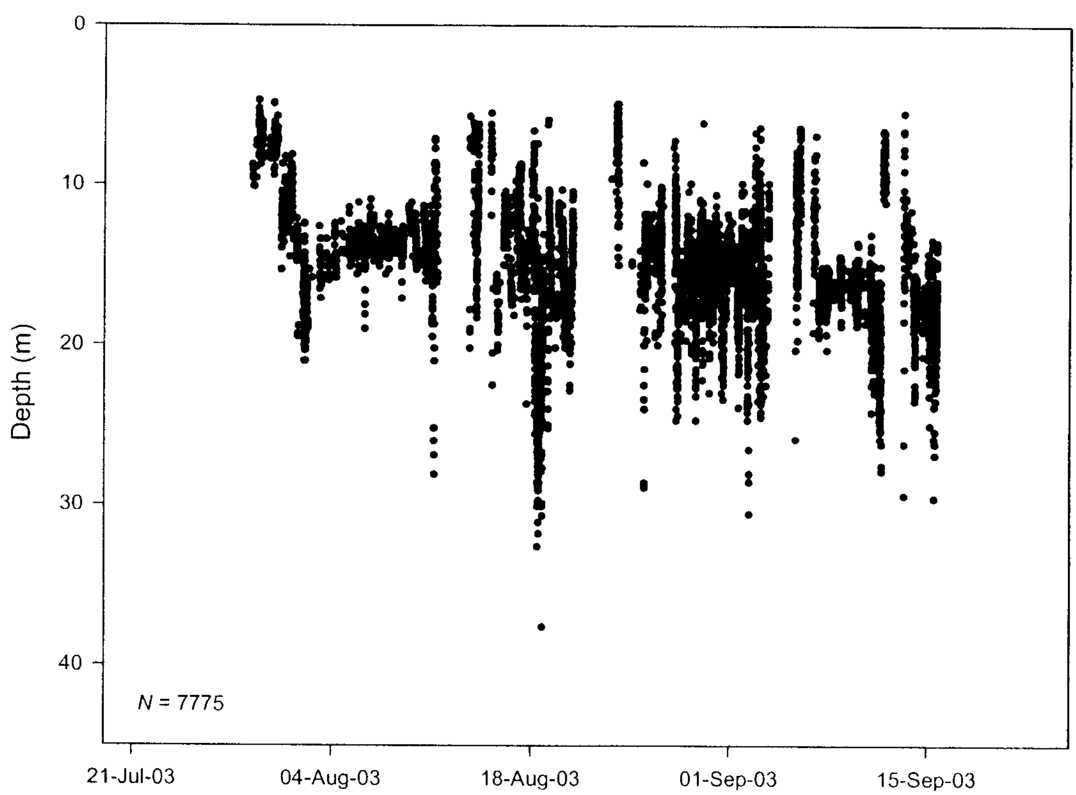
Appendix F continued.

ID 25 - 2003 Presence/Absence at USGS receiver locations
22 April 2003 - 13 October 2003

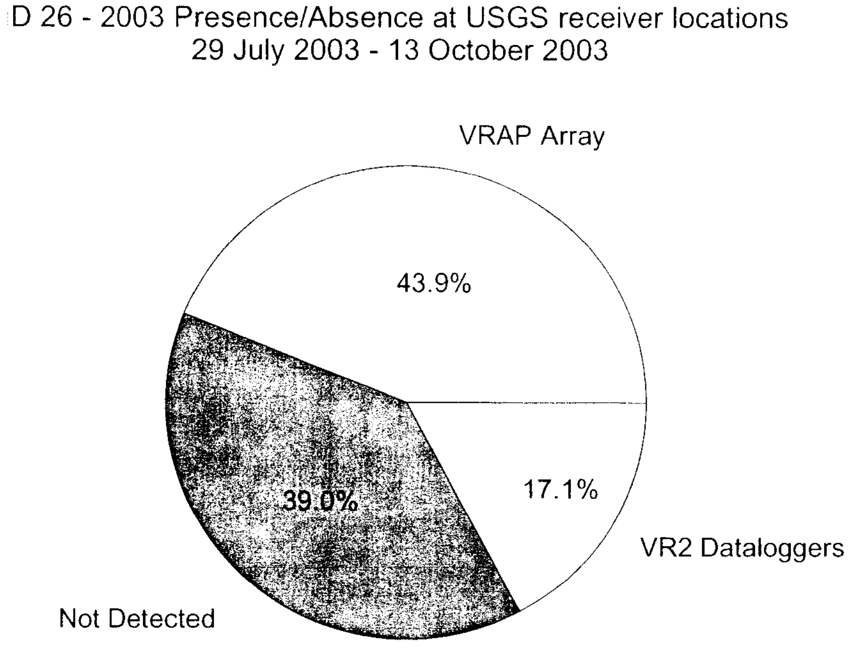


Appendix F continued.

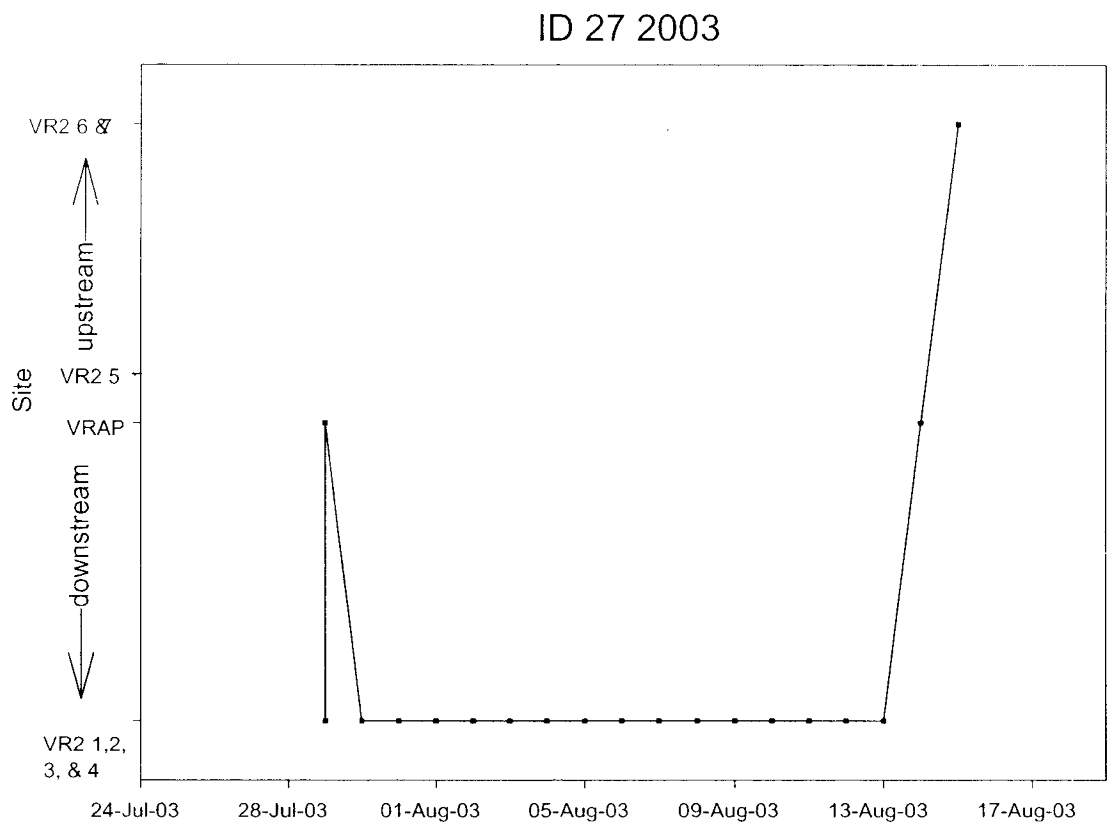


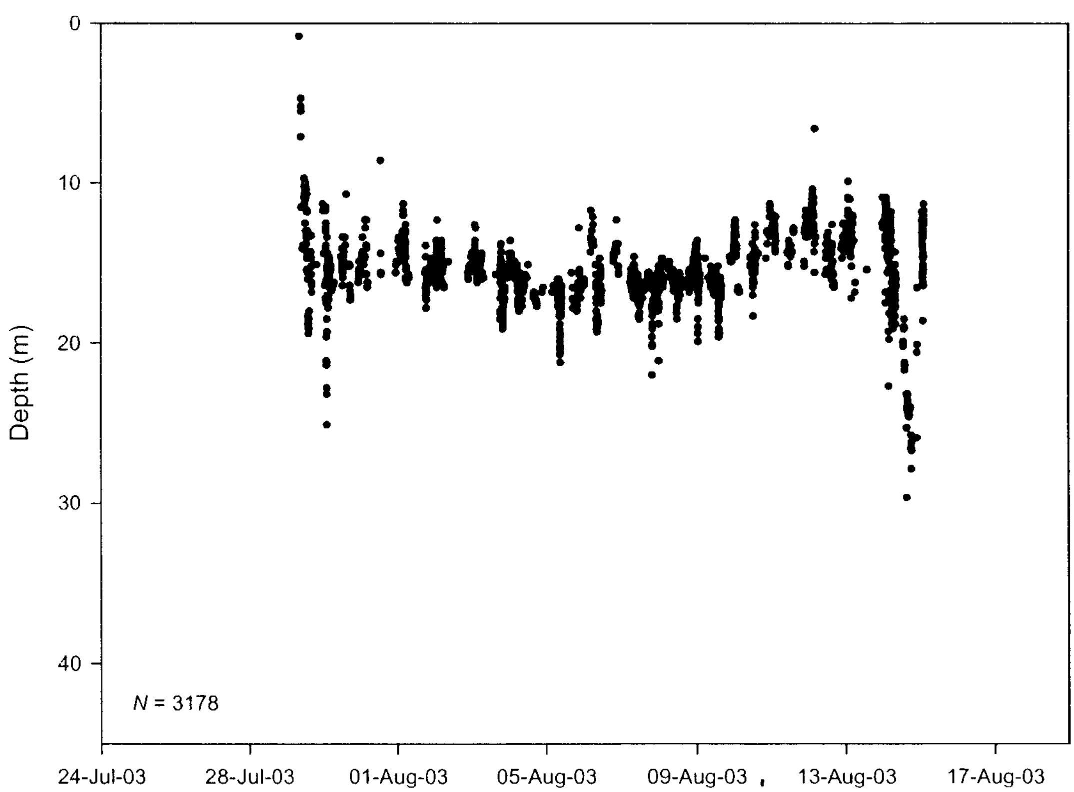


Appendix F continued.



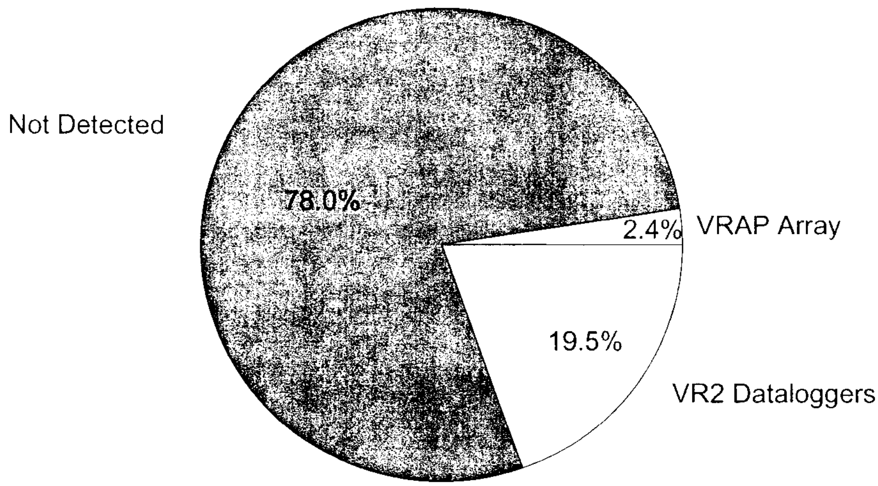
Appendix F continued.

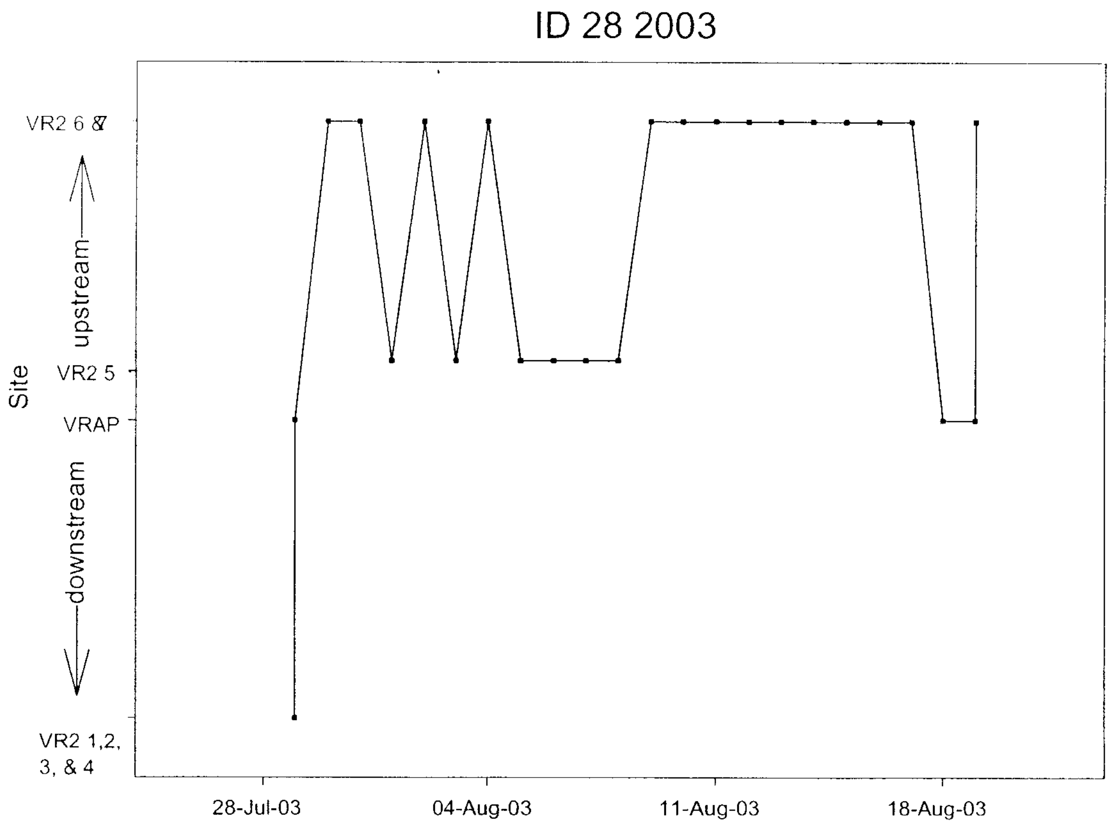


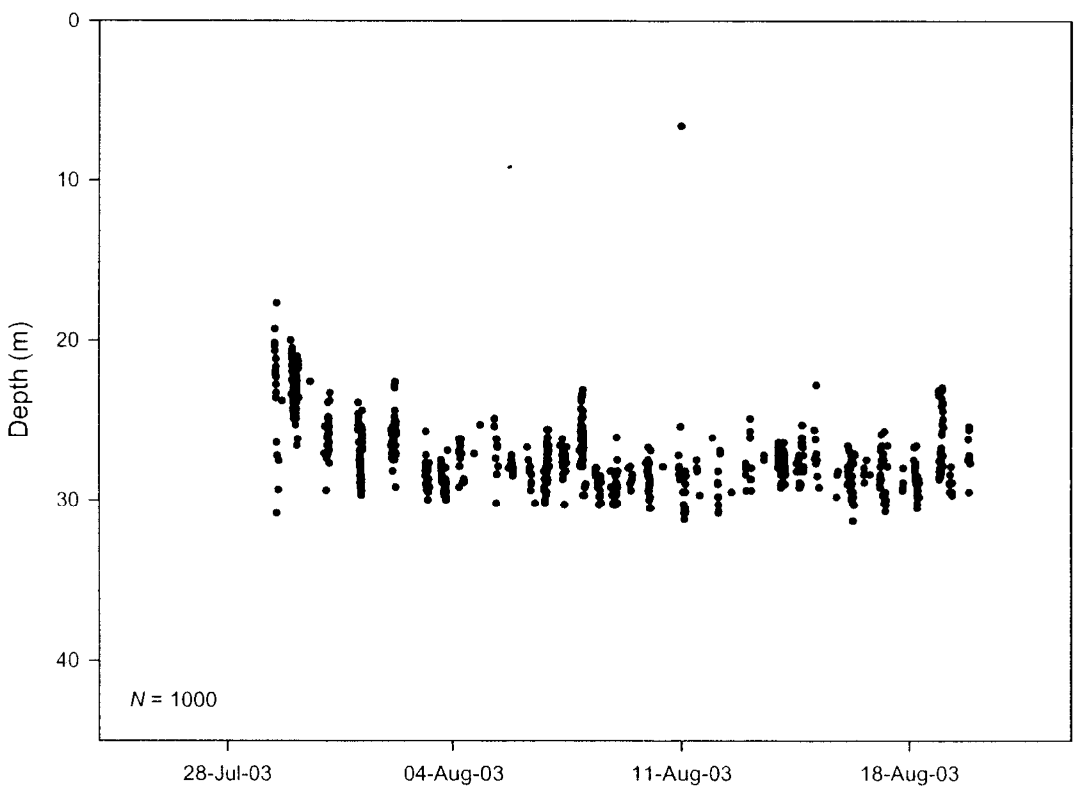


Appendix F continued.

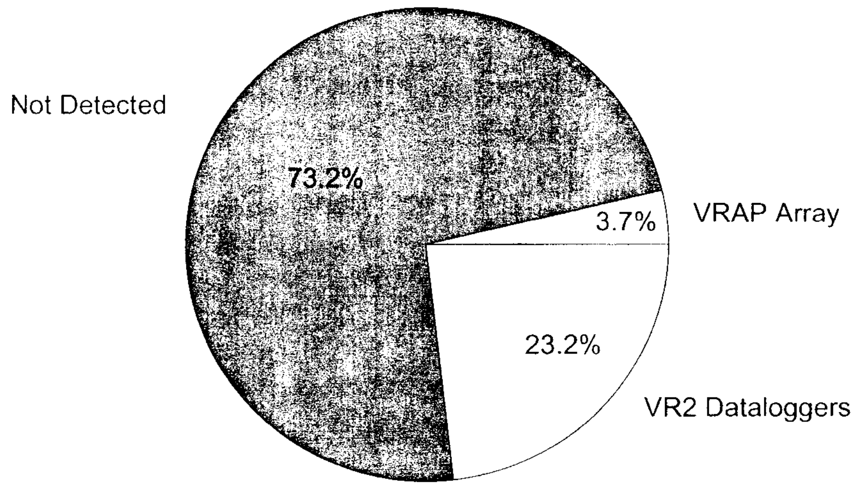
ID 27 - 2003 Presence/Absence at USGS receiver locations
29 July 2003 - 13 October 2003




ID 28 2003
VR2 6 & 7
upstream
Site
VR2 5
VRAP
downstream
VR2 1,2,
3, & 4
28-Jul-03
04-Aug-03
11-Aug-03
18-Aug-03

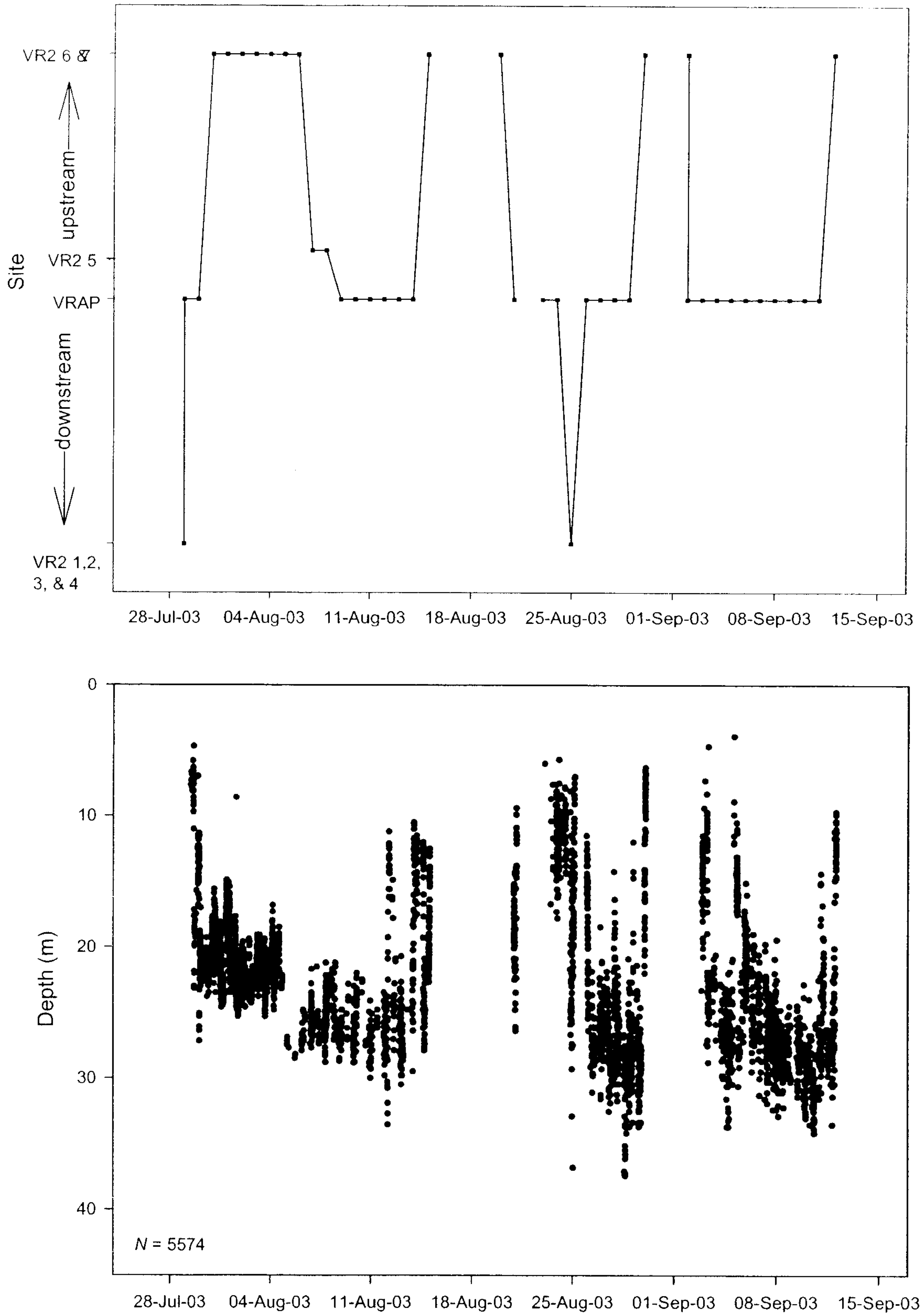

0
10
20
30
40
Depth (m)
N = 1000
28-Jul-03
04-Aug-03
11-Aug-03
18-Aug-03

ID 28 - 2003 Presence/Absence at USGS receiver locations
29 July 2003 - 13 October 2003



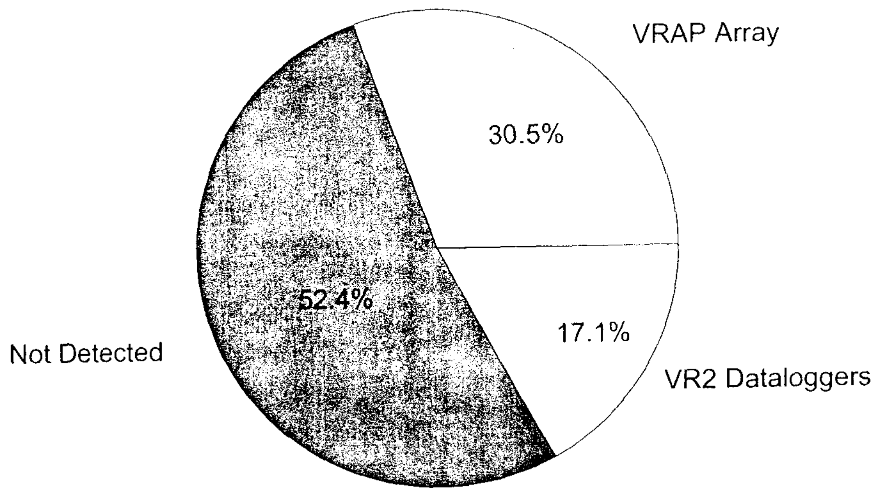
Appendix F continued.

ID 29 2003

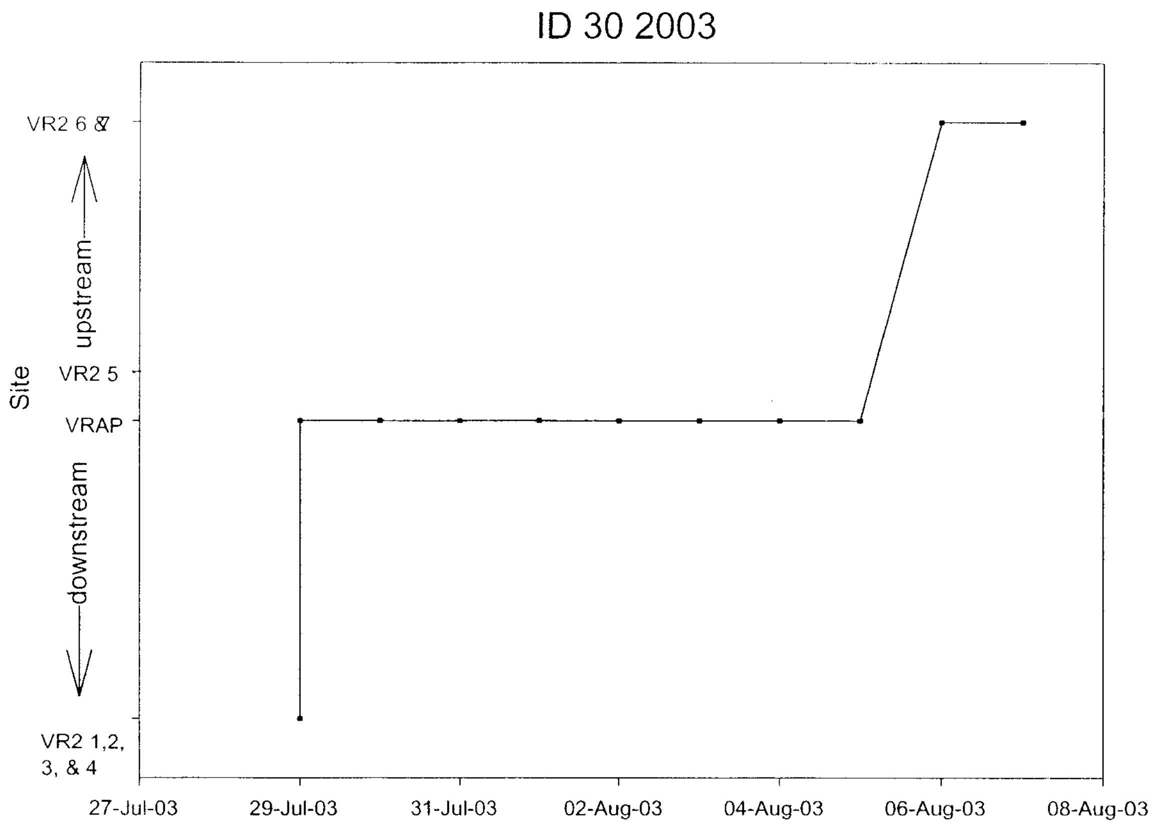


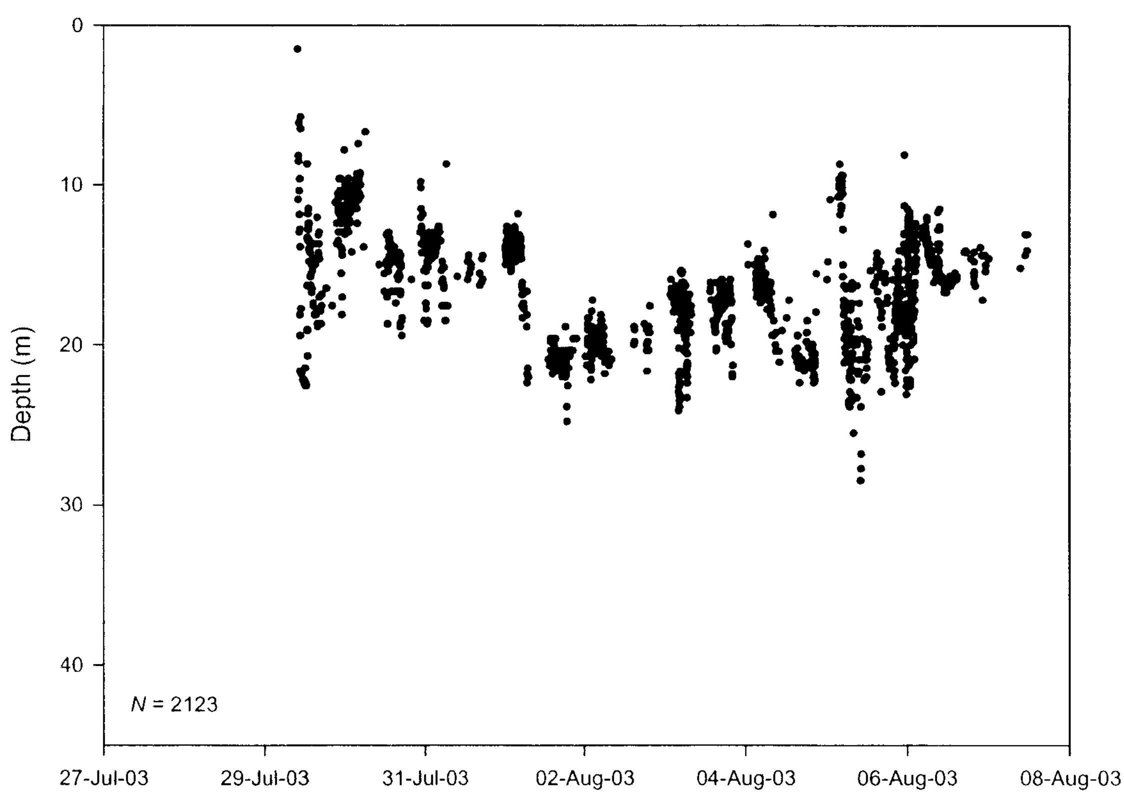
Appendix F continued.

D 29 - 2003 Presence/Absence at USGS receiver locations
29 July 2003 - 13 October 2003



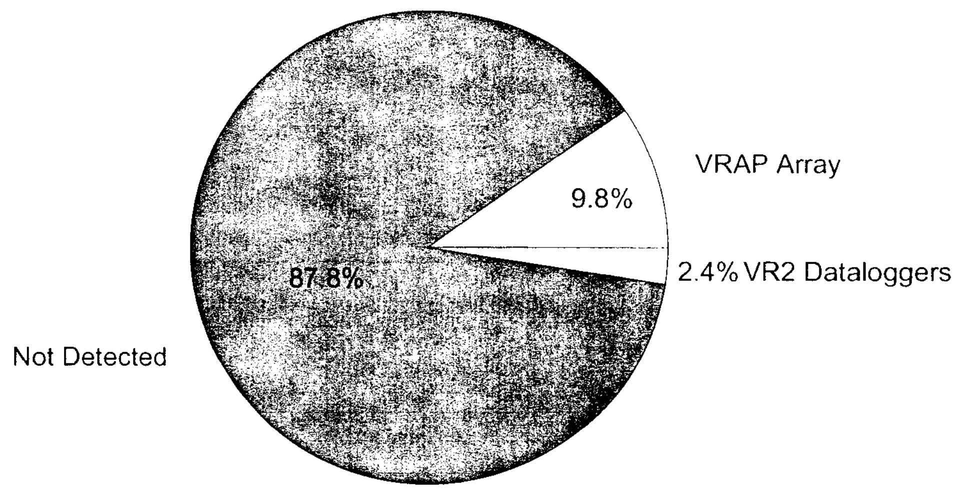
Appendix F continued.



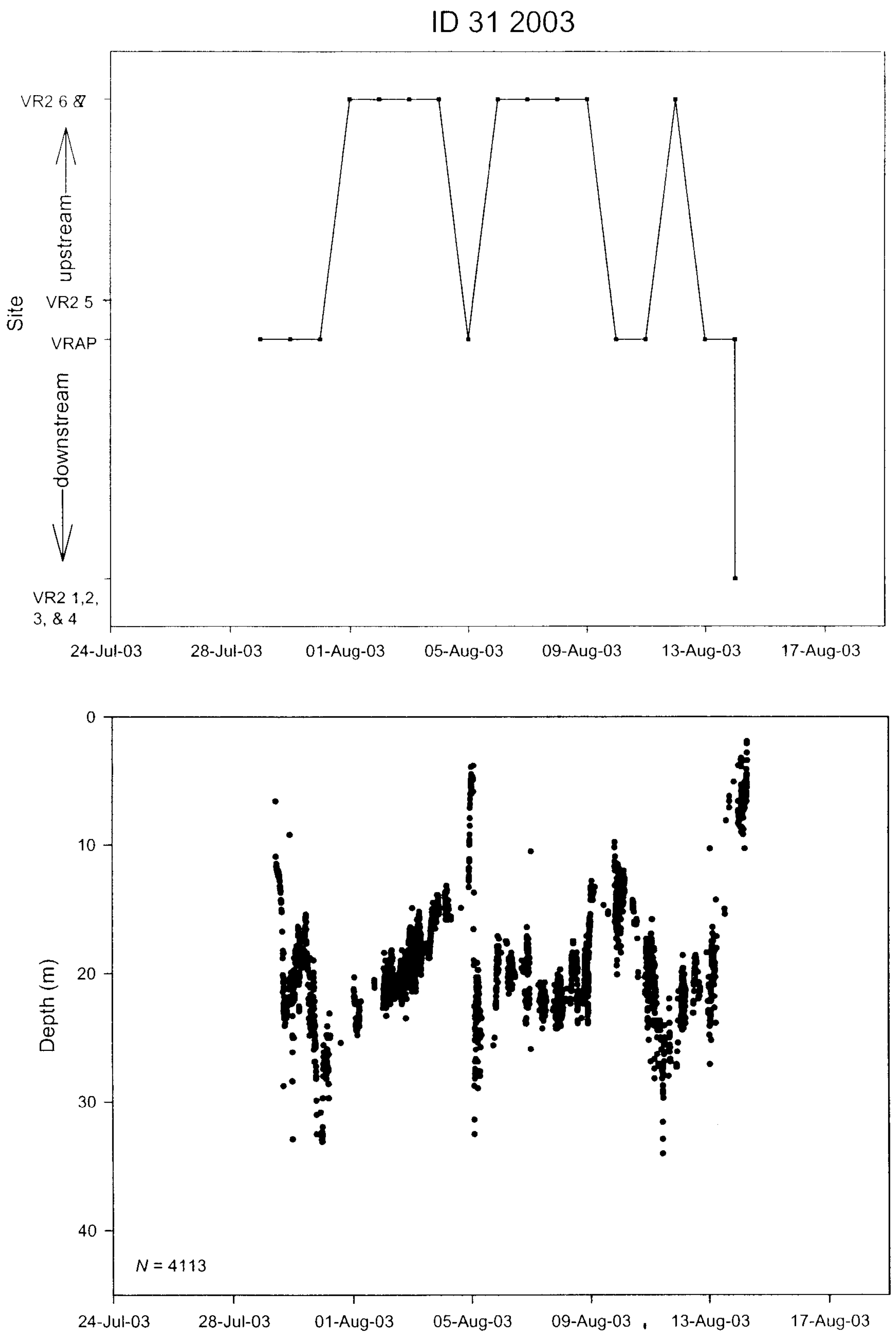


Appendix F continued.

ID 30 - 2003 Presence/Absence at USGS receiver locations
29 July 2003 - 13 October 2003

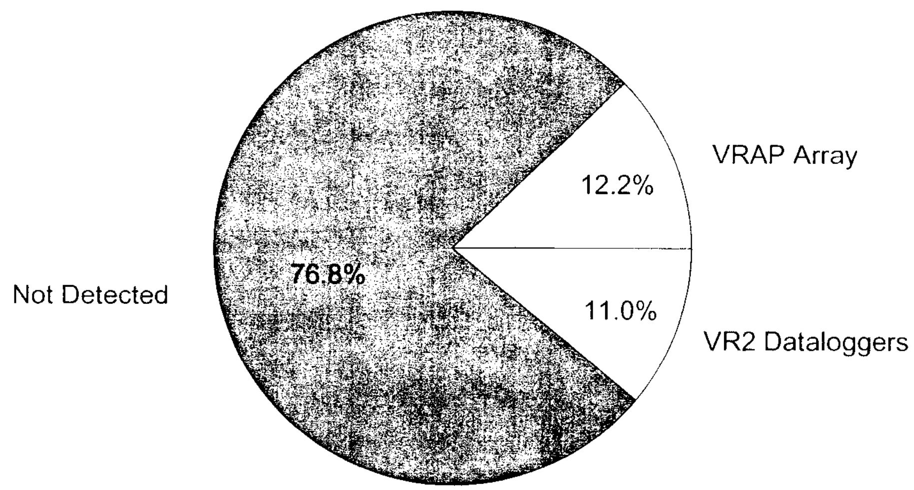


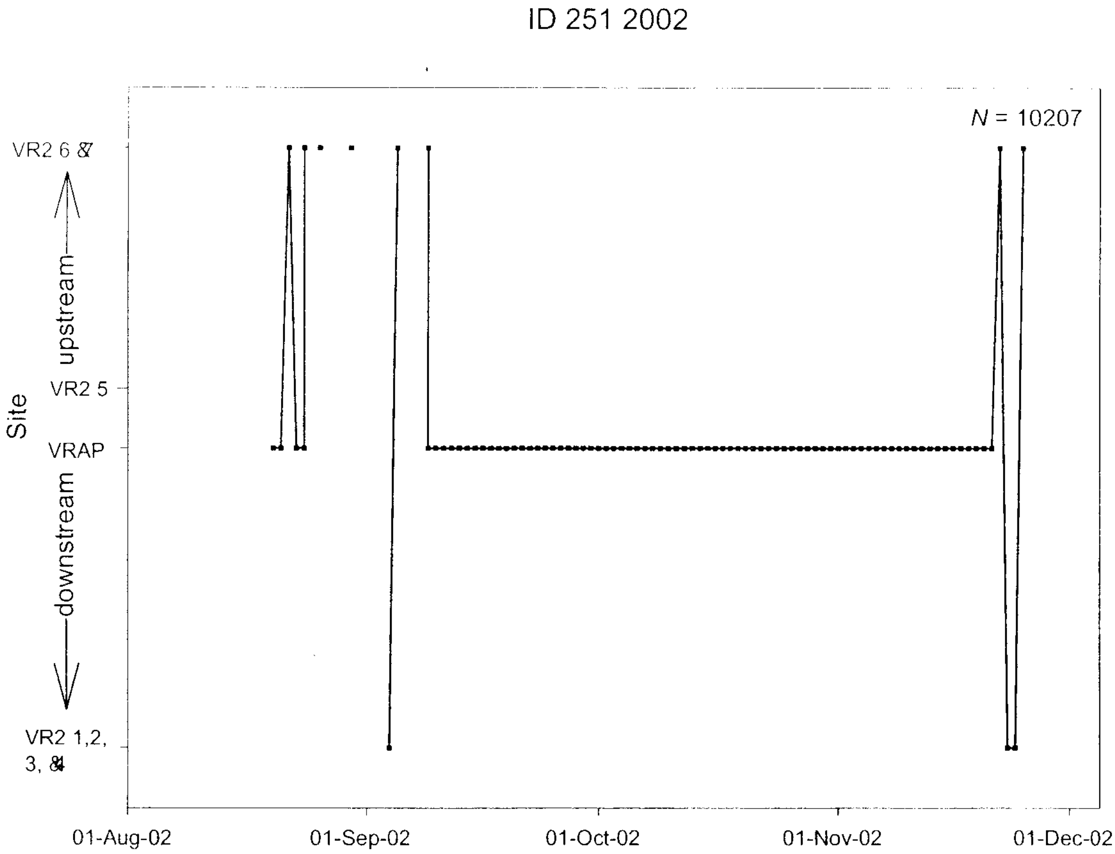
Appendix F continued.

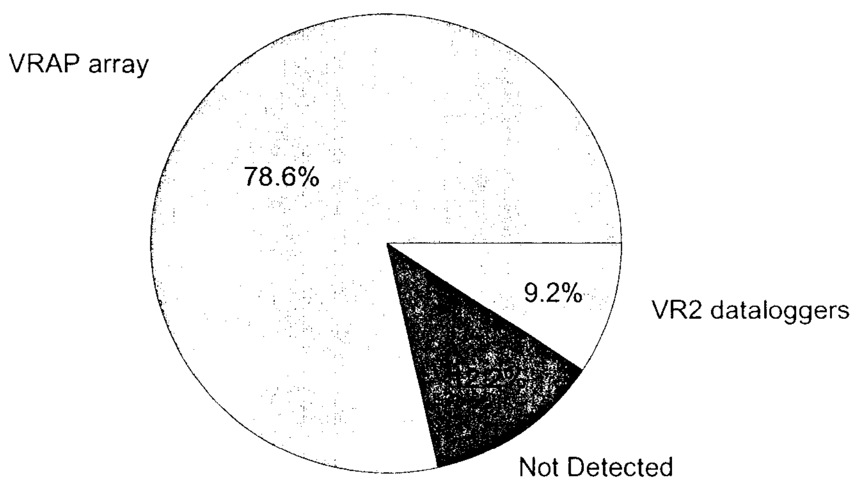


Appendix F continued.

ID 31- 2003 Presence/Absence at USGS receiver locations
29 July 2003 - 13 October 2003



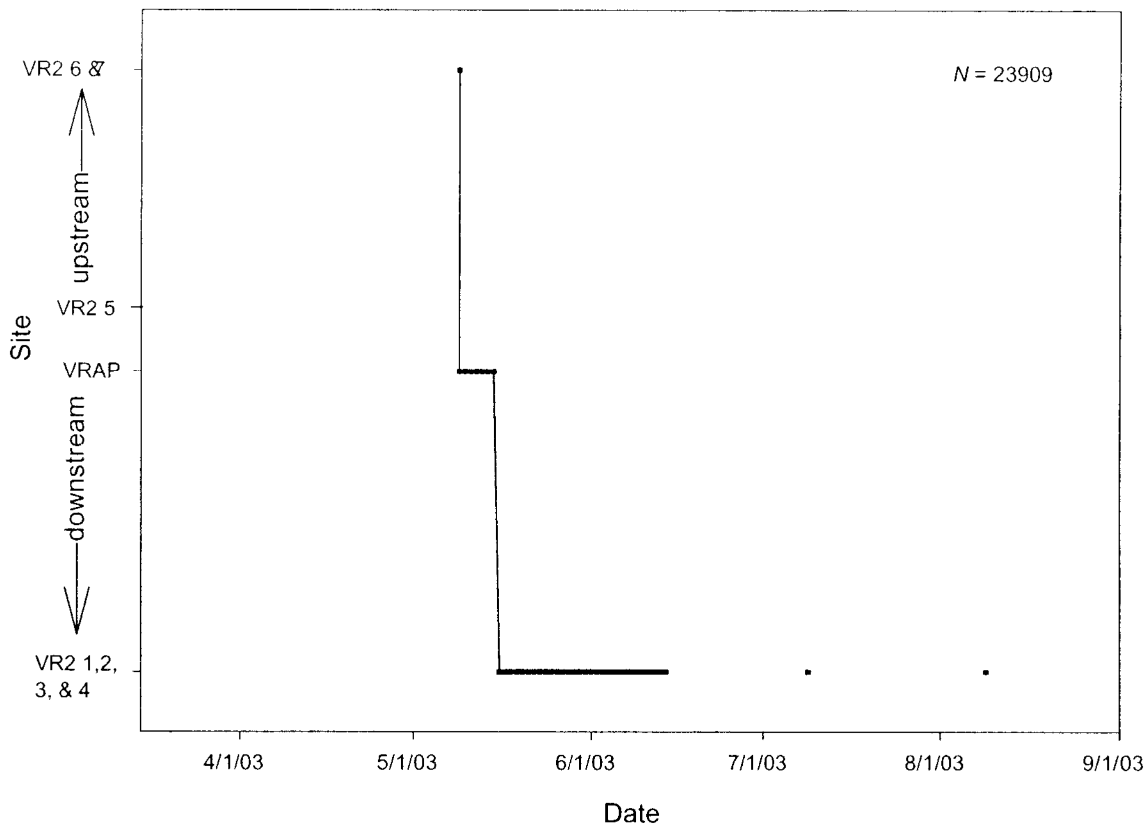


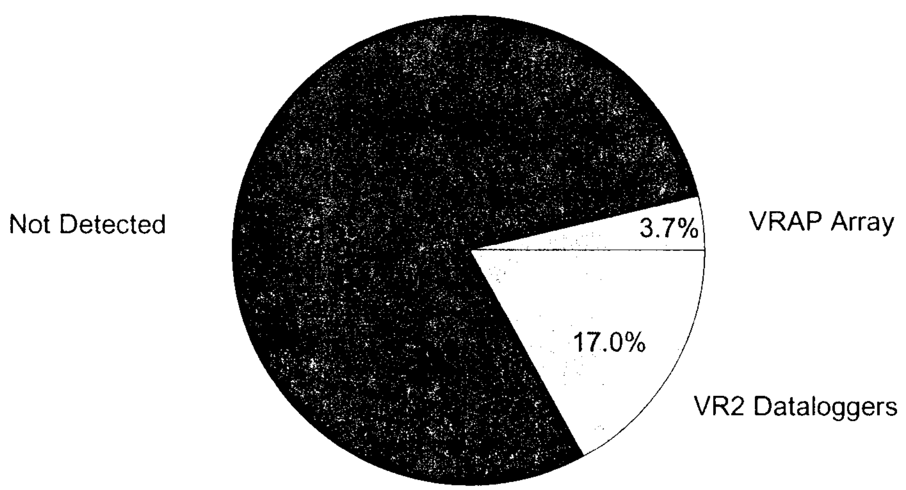


D 251 - Presence/Absence at USGS receiver locations
14 August 2002 to 26 November 2002

Appendix F continued.

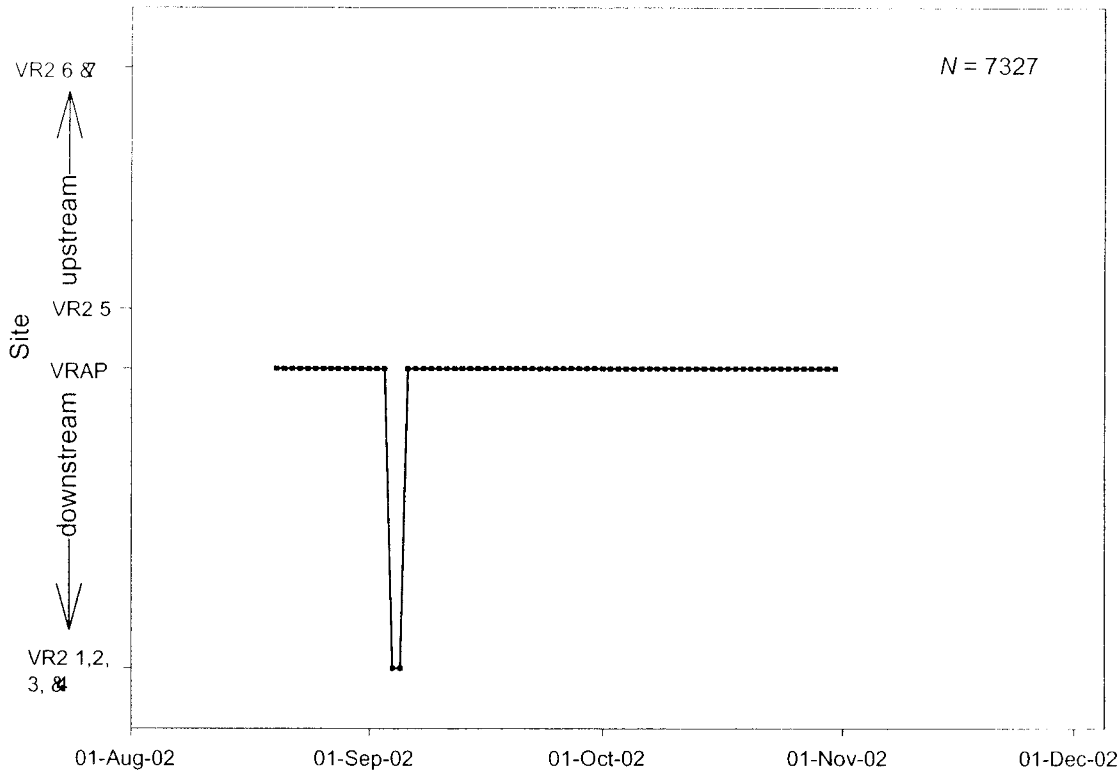
ID 251 2003

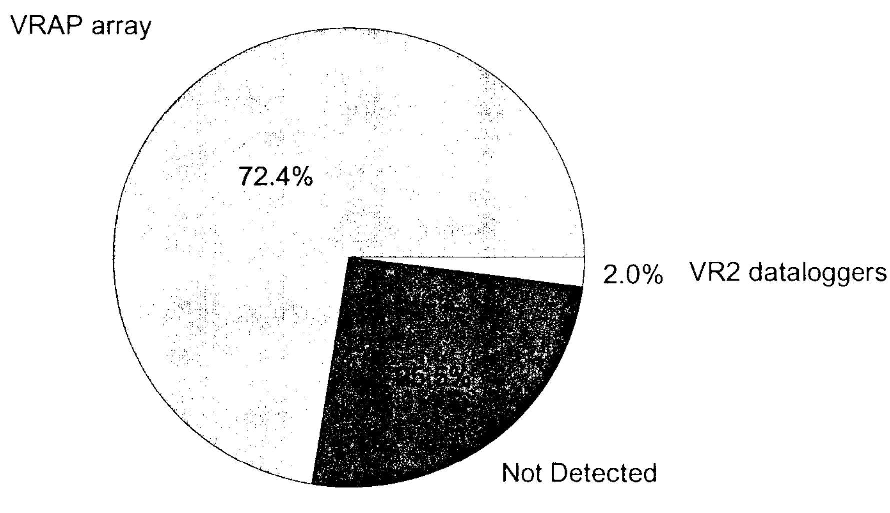




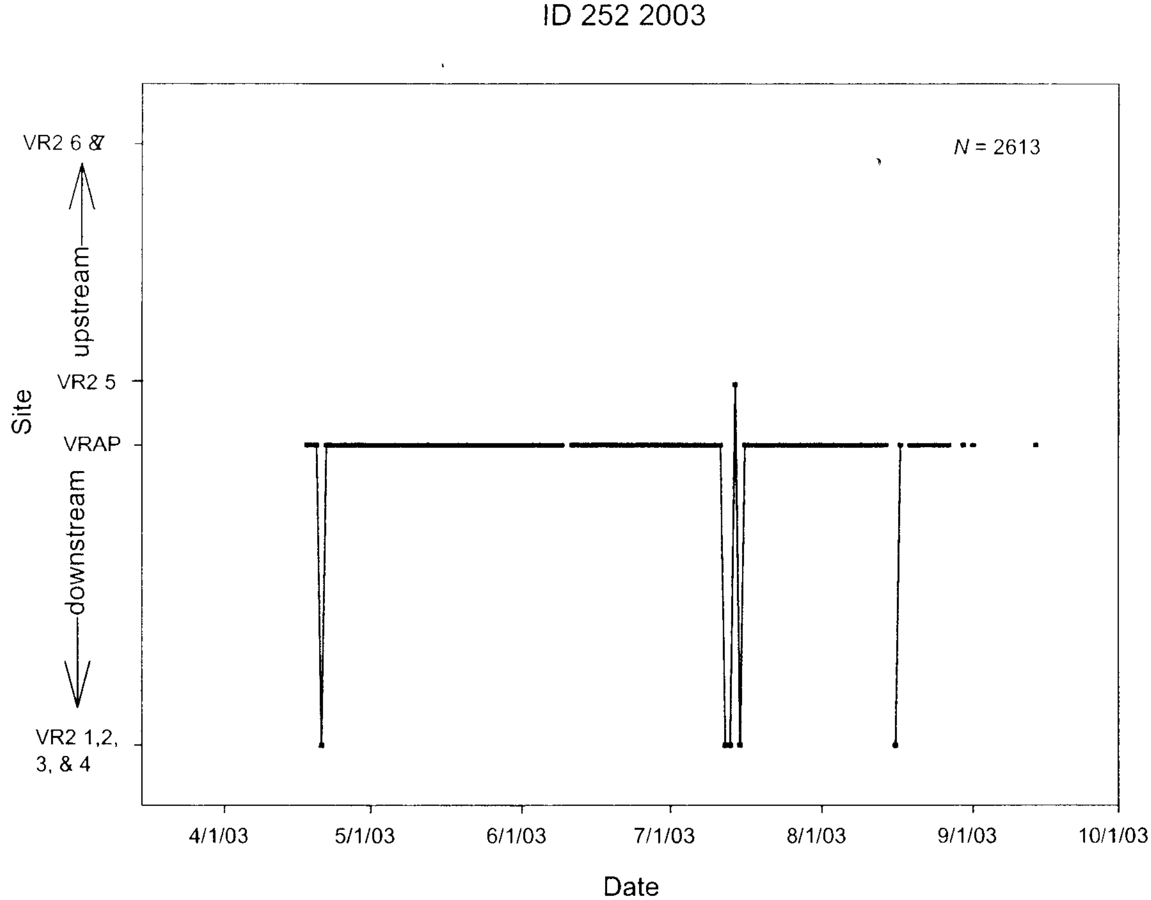
ID 251 - 2003 Presence/Absence at USGS receiver locations
8 April 2003 - 13 October 2003

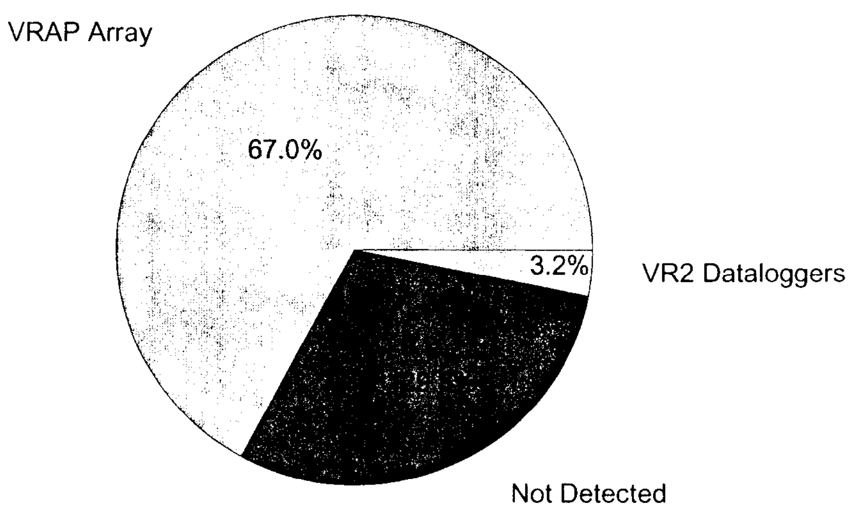
ID 252 2002



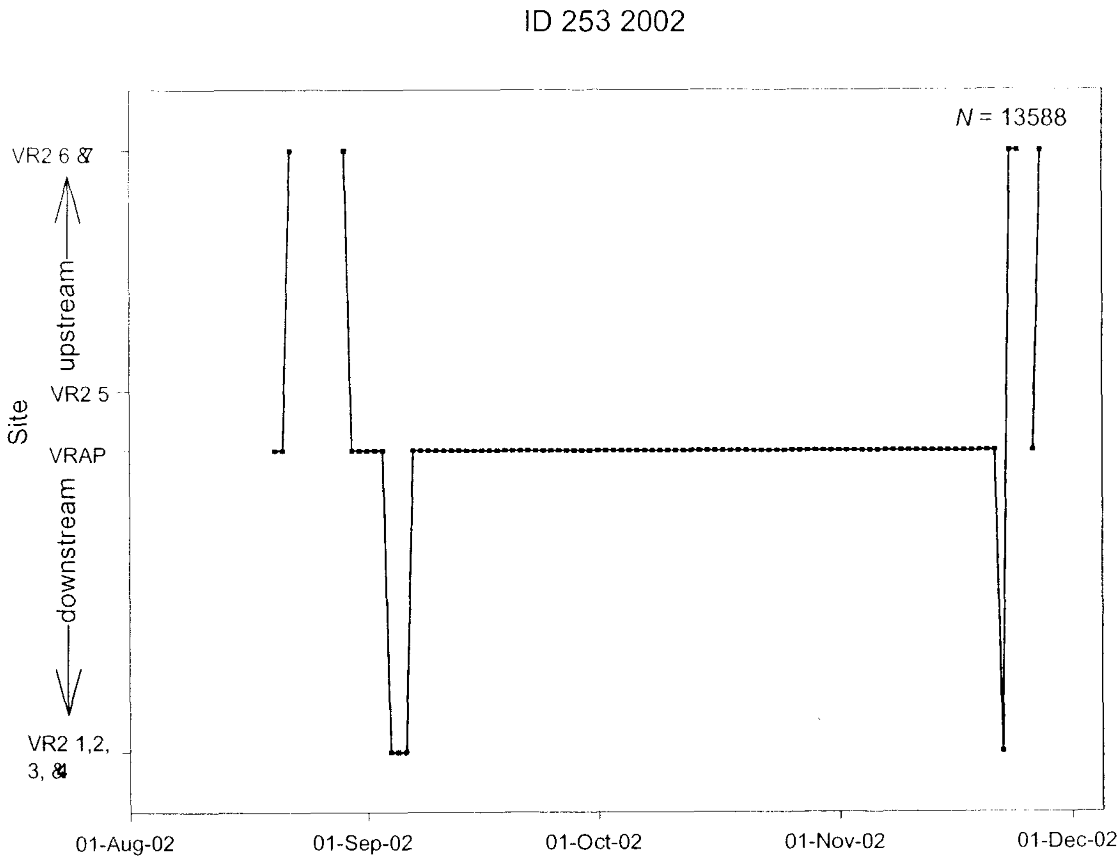


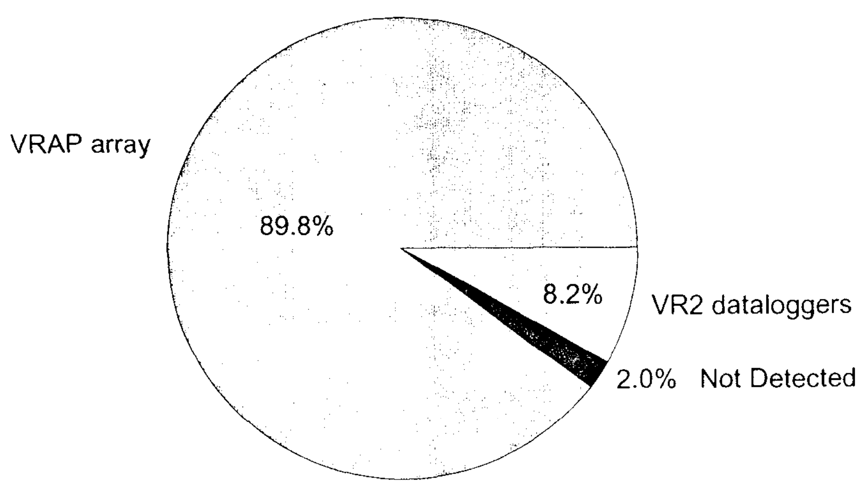
D 252 - Presence/Absence at USGS receiver locations
14 August 2002 to 26 November 2002





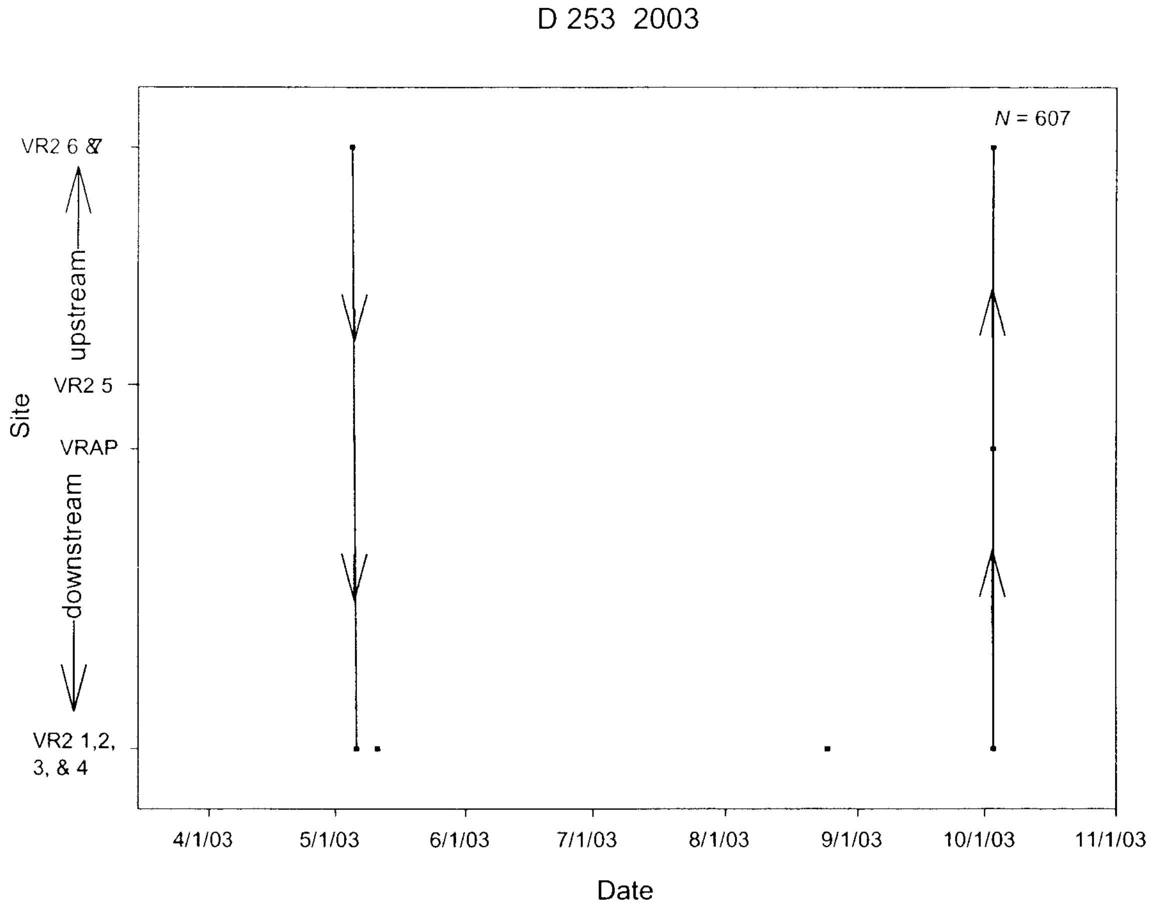
D 252 - 2003 Presence/Absence at USGS receiver locations
8 April 2003 - 13 October 2003

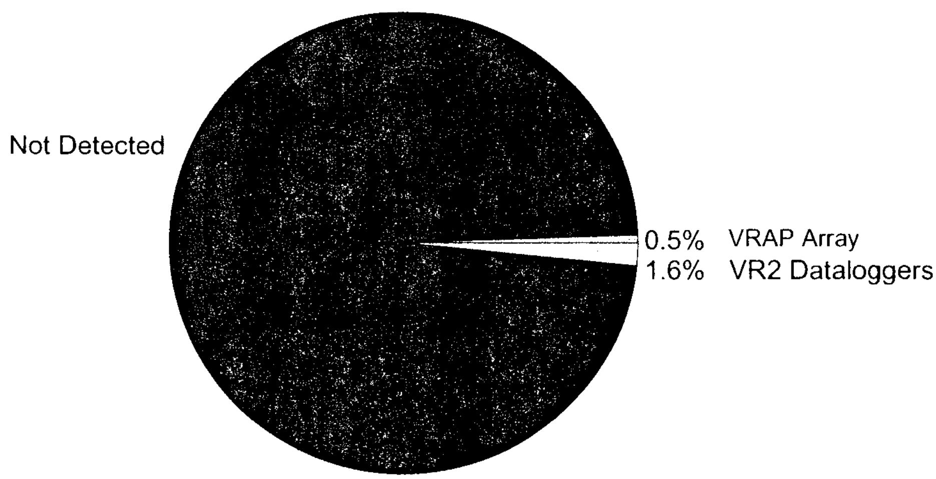




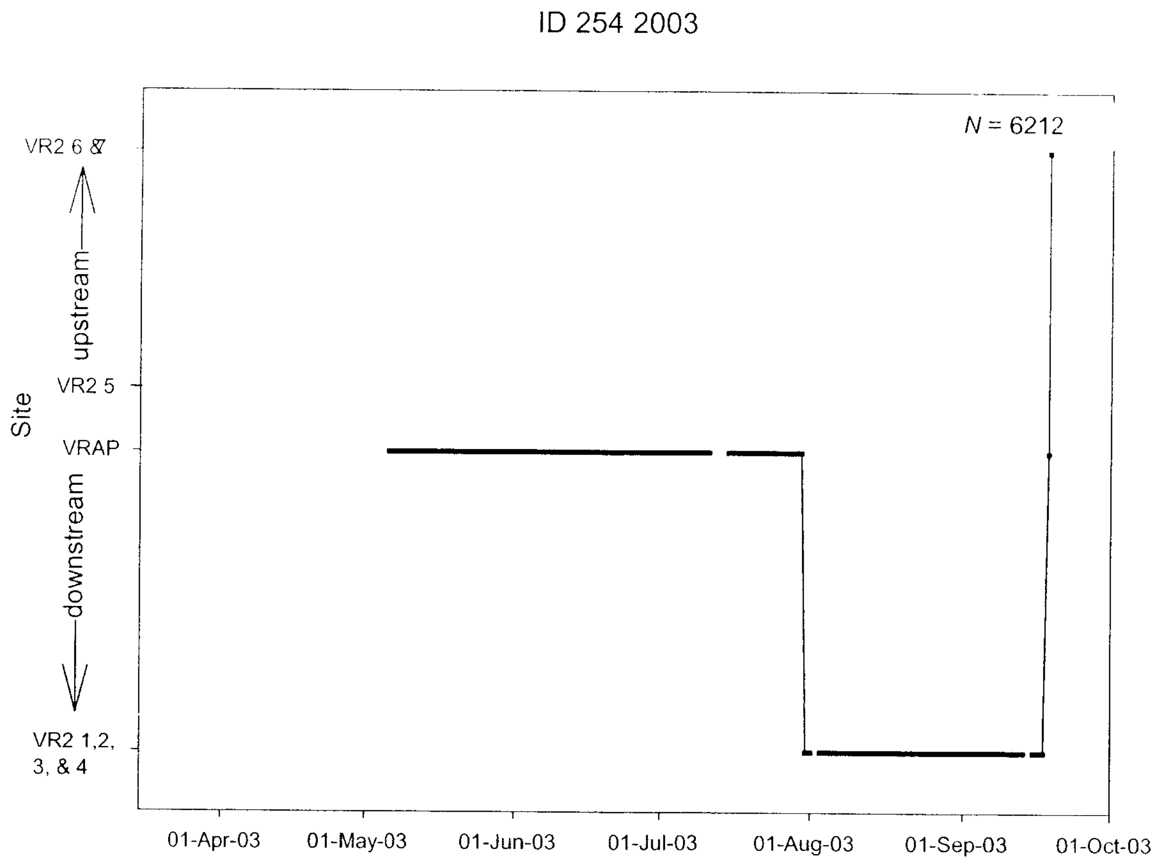
D 253 - Presence/Absence at USGS receiver locations
14 August 2002 to 26 November 2002

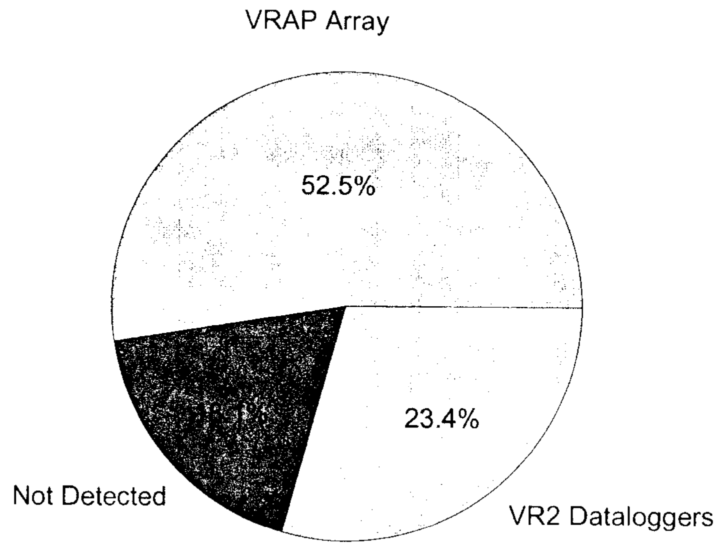
Appendix F continued.



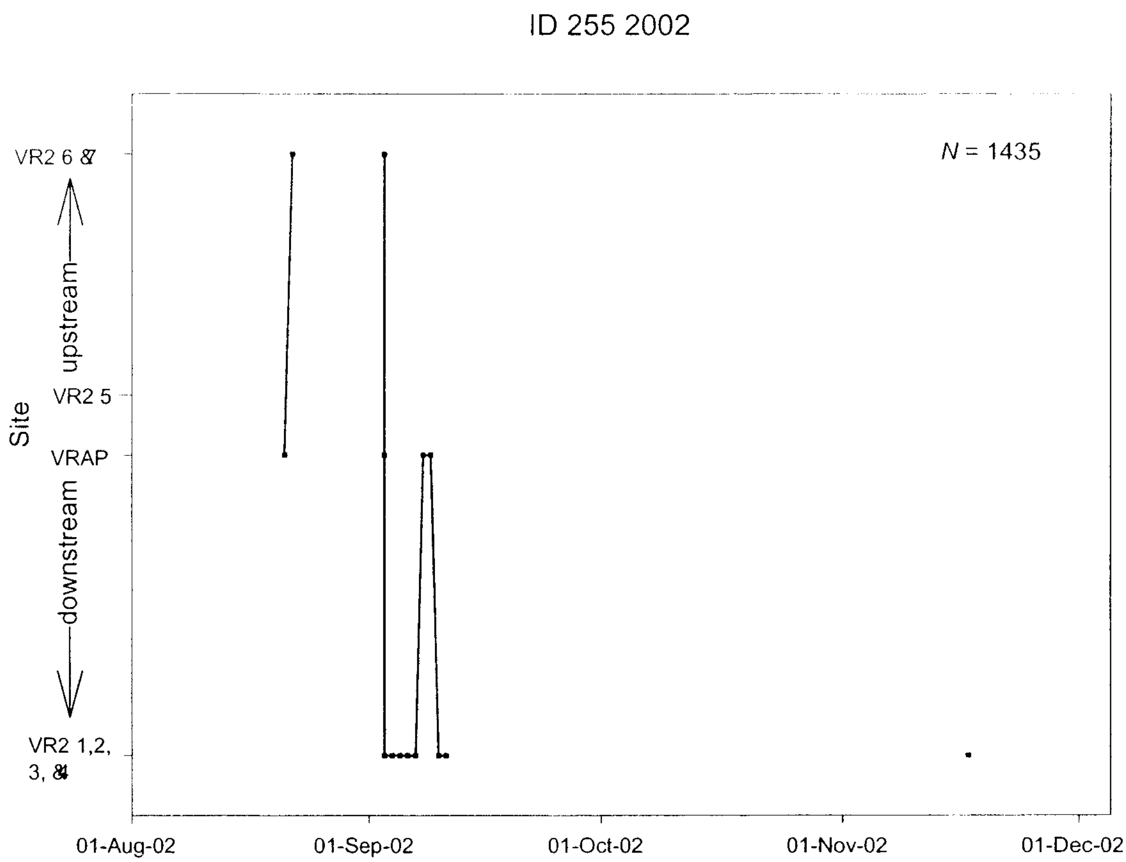


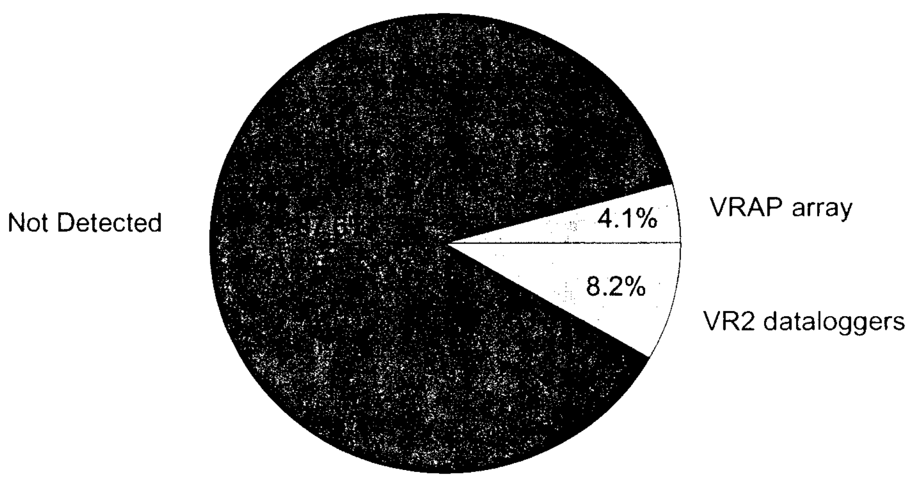
ID 253 2003 Presence/Absence at USGS reciever locations
(8 April 2003 - 13 October 2003)



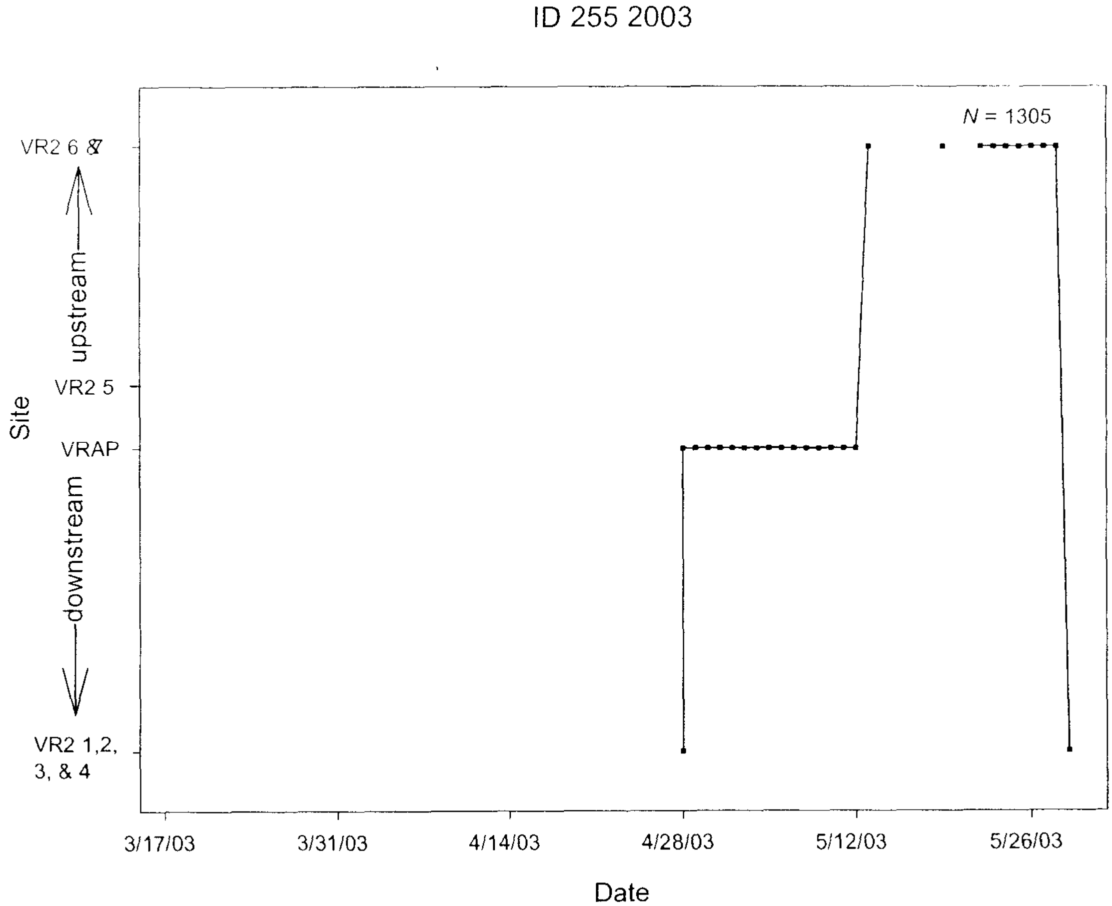


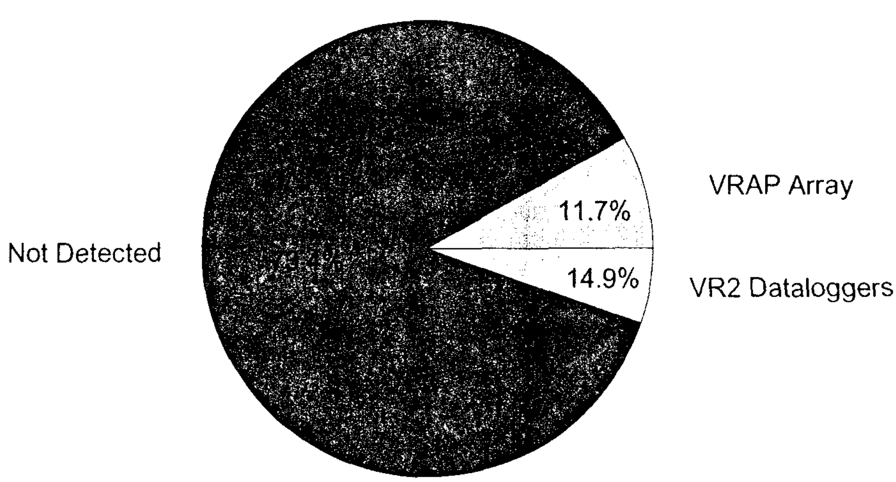
ID 254 - 2003 Presence/Absence at USGS receiver locations
8 April 2003 - 13 October 2003



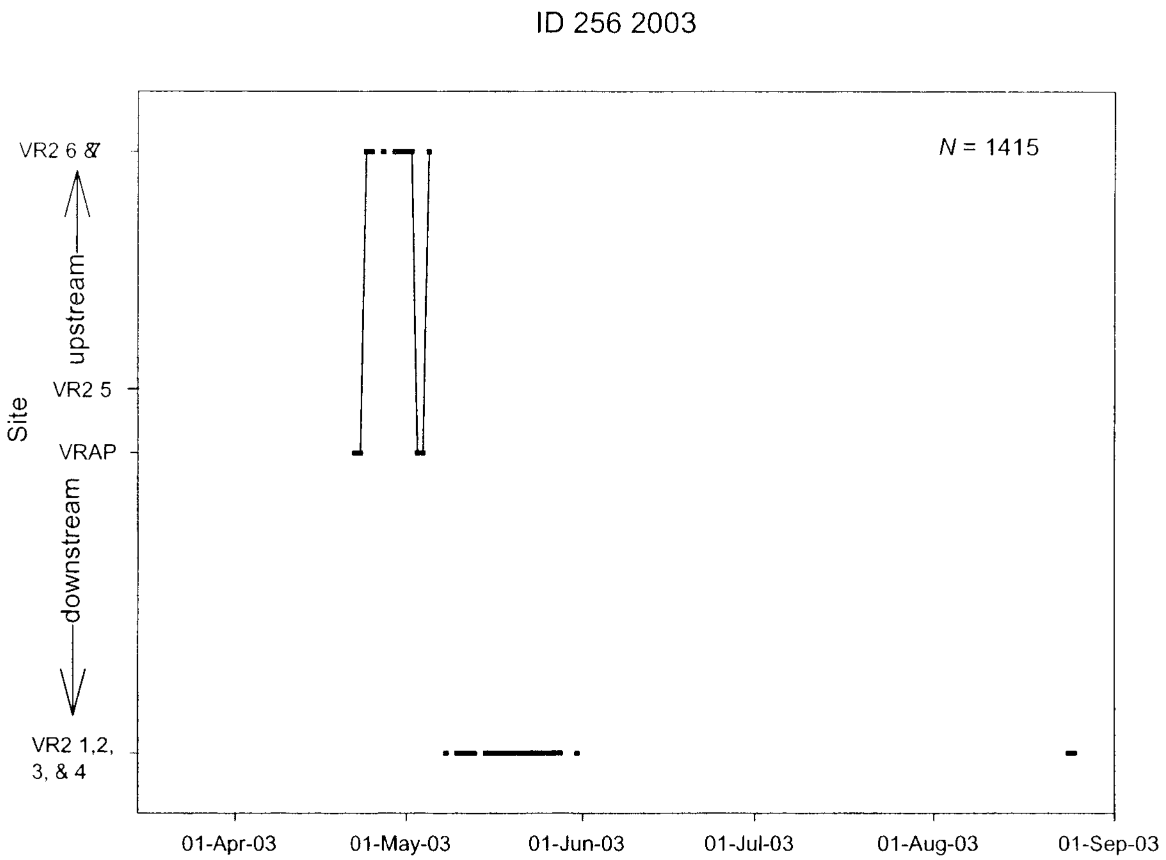


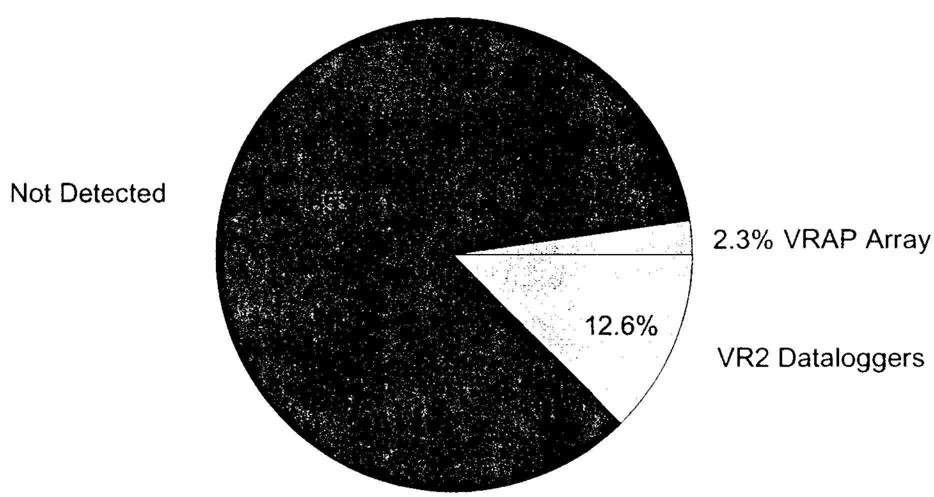
D 255 - Presence/Absence at USGS receiver locations
14 August 2002 to 26 November 2002





D 255 2003 Presence/Absence at USGS reciever locations
(8 April 2003 - 13 October 2003)





D 256 - 2003 Presence/Absence at USGS receiver locations
8 April 2003 - 13 October 2003