Distribution and Relative Abundance of Deep-Water Redds for Spawning Fall Chinook Salmon

at Selected Study Sites in the Hanford Reach of the Columbia River

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COASTAL ZONE AND ESTUARINE STUDIES

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INTRODUCTION

Main-stem dams have provided many benefits relating to irrigation, flood control, water transportation, and hydroelectric power in the Columbia Basin, however, they have also inundated, and thus removed from production, many hundreds of miles of the main-stem spawning habitat predominantly used by fall chinook salmon (Oncorhynchus tshawytscha) (Fulton 1968). Since the construction of Bonneville Dam in 1938, development of main-stem and tributary dams as well as water storage projects have eliminated more than half the anadromous salmonid spawning habitat (from 163,200 to 73,280 mile^2) throughout the Columbia Basin (Becker 1985).

By 1968, the entire main-stem Columbia River from Bonneville Dam at River Mile (RM) 145 to the Canadian border was impounded behind a succession of dams and reservoirs except for a 52-mile long section extending from the upper end of the McNary Dam Reservoir (Lake Wallula) near Richland, Washington, at about River Mile (RM) 345 to Priest Rapids Dam at RM 397. While this section of the river is essentially free-flowing, flow rates are regulated at Priest Rapids Dam, primarily for power peaking (Becker et al. 1981). Commonly termed the Hanford Reach (Fig. 1), it provides the major spawning area for a significant population of "upriver bright" fall chinook salmon (Watson 1970; Chapman et al. 1986). Because these salmon retain their color and flesh quality throughout much of their upstream spawning migration, and the magnitude of the spawning escapement passing McNary Dam has increased over two-fold since 1984, they are becoming more and more valuable to the Columbia River and ocean fisheries.

Since 1947, numbers of fall chinook salmon redds (gravel "nests") in the Hanford Reach have been estimated primarily through aerial observations and

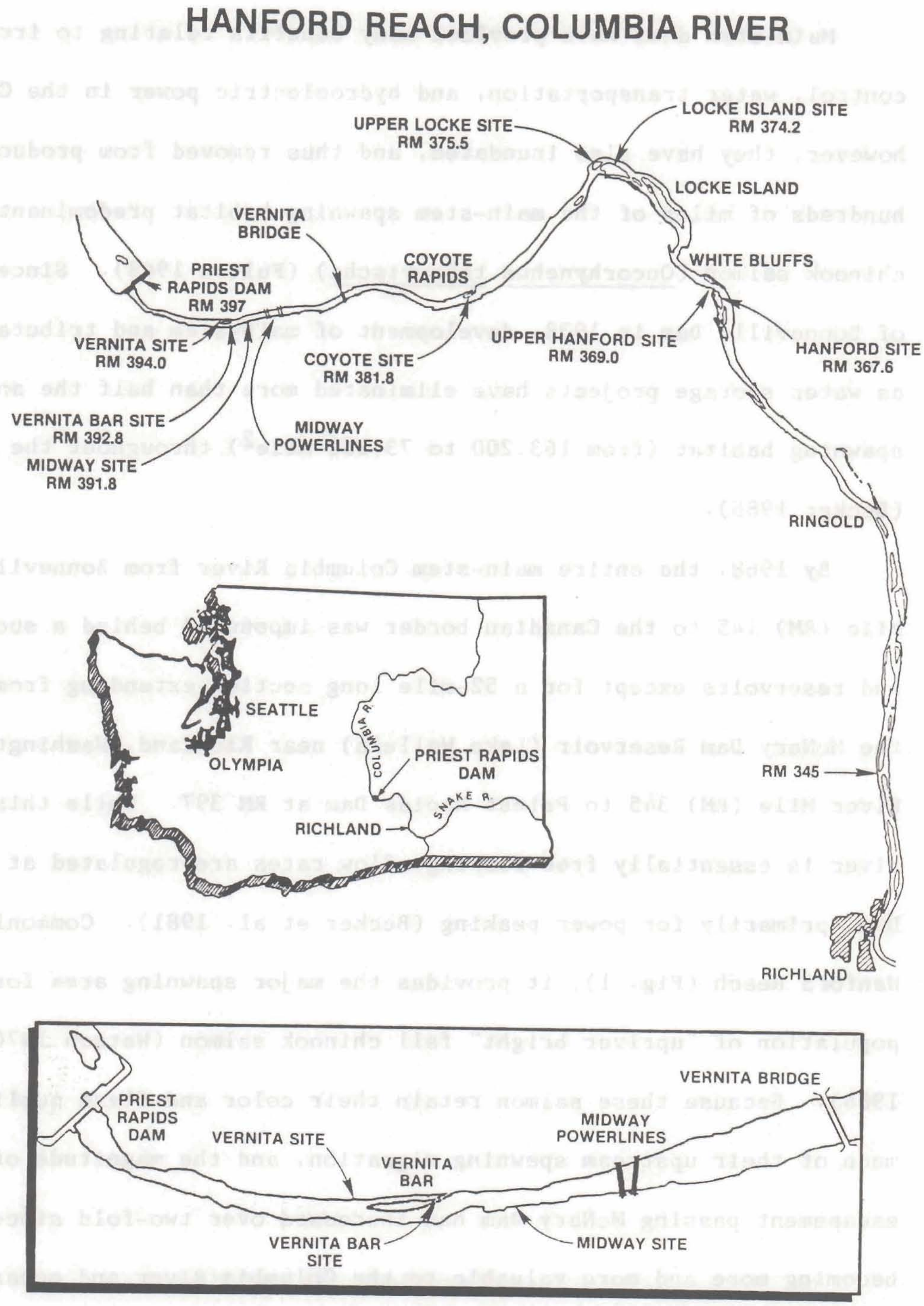

Figure 1.--Vicinity map of the Hanford Reach of the Columbia River showing the approximate river mile and designated name for the eight study sites for the deep-water survey of fall chinook salmon spawning, 1986.

limited ground counts. These estimates do not include data on the numbers of redds located in water too deep to be detected from the air or ground (Watson 1970, 1976). It is generally accepted that redds at depths exceeding about 8-10 ft cannot be detected with aerial, ground, or boat observations. These traditional methods of redd detection depend on water turbidity, flow levels, cloud cover, surface winds, and angle and intensity of sunlight (Watson 1970, 1976; Chapman et al. 1986).

In recent years, spawning of fall chinook salmon in the Hanford Reach has received considerable attention. The effects of powerhouse operations at Priest Rapids Dam and the resulting downstream flow conditions during salmonid spawning and incubation are monitored closely by Grant County Public Utility District (PUD) and fishery agencies.

A new plan warranting similar concern is the shallow-draft navigation channel through the Hanford Reach proposed by the U.S. Army Corps of Engineers (COE) to accommodate river barge transportation between the Tri-Cities area (Pasco; Kennewick; and Richland, Washington, RM 345) and Wenatchee, Washington (RM 470).

Before the COE can proceed with this project, however, they are required to determine the effects of the proposed navigation plan on spawning salmonids, egg incubation, and fry survival. One of the necessary initial steps is to determine if there is significant deep water spawning in the vicinity of the proposed navigation channel. If there is little deep-water spawning, the overall direct impact on spawning might be less severe since the proposed channel would require only minimal dredging to maintain a 14-ft channel. The shallow channel is sufficient because barge traffic would only be allowed during periods of maximum power peaking at Priest Rapids Dam (peak river-flows through the Hanford Reach). However, if deep-water spawning is extensive, the potential direct impact would warrant serious attention.

Descriptions of extensive deep-water spawning by chinook salmon in river depths to 12-15 ft in the main-stem Columbia River downstream from Kettle Falls, Washington (RM 697.8), were given by Chapman (1943). Chambers (1955) believed that chinook salmon spawned as deep as 24 ft in the main-stem Columbia River. Meekin (1967) studied main-stem spawning near Brewster, Washington (RM 530.0), and found redds in depths ranging from shallow water to approximately 30 ft.

At Vernita Bar, located approximately 4 mi downstream from Priest Rapids Dam at about RM 393, Chapman et al. (1983) hypothesized that a large but undefined portion of the spawning area extended beyond the depths visible from boat or aircraft. They were unable to accurately estimate redd density in deep water, but did employ observations by scuba divers to define limits of the distribution and depth of spawning. Scuba diving was hampered by the high velocities (usually about 3-6.5 ft/s) and limited visibility (about 10 ft). However, they determined that fall chinook salmon at Vernita Bar spawned in depths as great as 35 ft during high flow periods (Chapman[1]).

In the fall of 1986, research divers from the National Marine Fisheries Service (NMFS), National Oceanic and Atmospheric Administration (NOAA), in conjunction with Horton Dennis and Associates (HDA), consulting engineers and surveyors to the COE, conducted a spawning survey in the Hanford Reach partially funded by the Seattle District of the COE. The objectives of this study were to survey and map, with particular attention to deeper water, the distribution and relative abundance of fall chinook salmon redds in representative sample areas

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[1]D. W. Chapman, Consultants Inc., 3180 Airport Way, Boise ID 83705; pers. commun. 1987.

of the Hanford Reach of the Columbia River. The objectives were accomplished within the following tasks:

1. Develop a topographical map showing the depth contours for each study site.

2. Develop a map for each study site showing type and size of rock material on the river bed.

3. Develop a map showing the distribution of individual redds and concentrated spawning beds within each study site.

4. Develop a map or tabular data of surface and near-bottom flow velocities at each study site (added to the objectives late in the study).

METHODS

Spawning Survey Team

Diving Team

The NOAA-certified NMFS diving team was composed of fishery biologists and maintenance personnel who had secondary duties as research divers, boat operators, and diver support personnel. Many of the members of the NMFS diving team had considerable experience with the low visibility, cold water, and fast river current in the Columbia and Snake rivers (Swan et al. 1986). In this study, the NMFS diving team performed standard snorkel and scuba diving observations and operated a towed, two-diver sled for underwater observations of the river bottom and salmon spawning activity (Fig. 2). A description of the sled and its operations is contained in Swan (1987). All diving operations were conducted according to NOAA Diving Regulations, contained in the NOAA Diving Manual (Miller 1979).

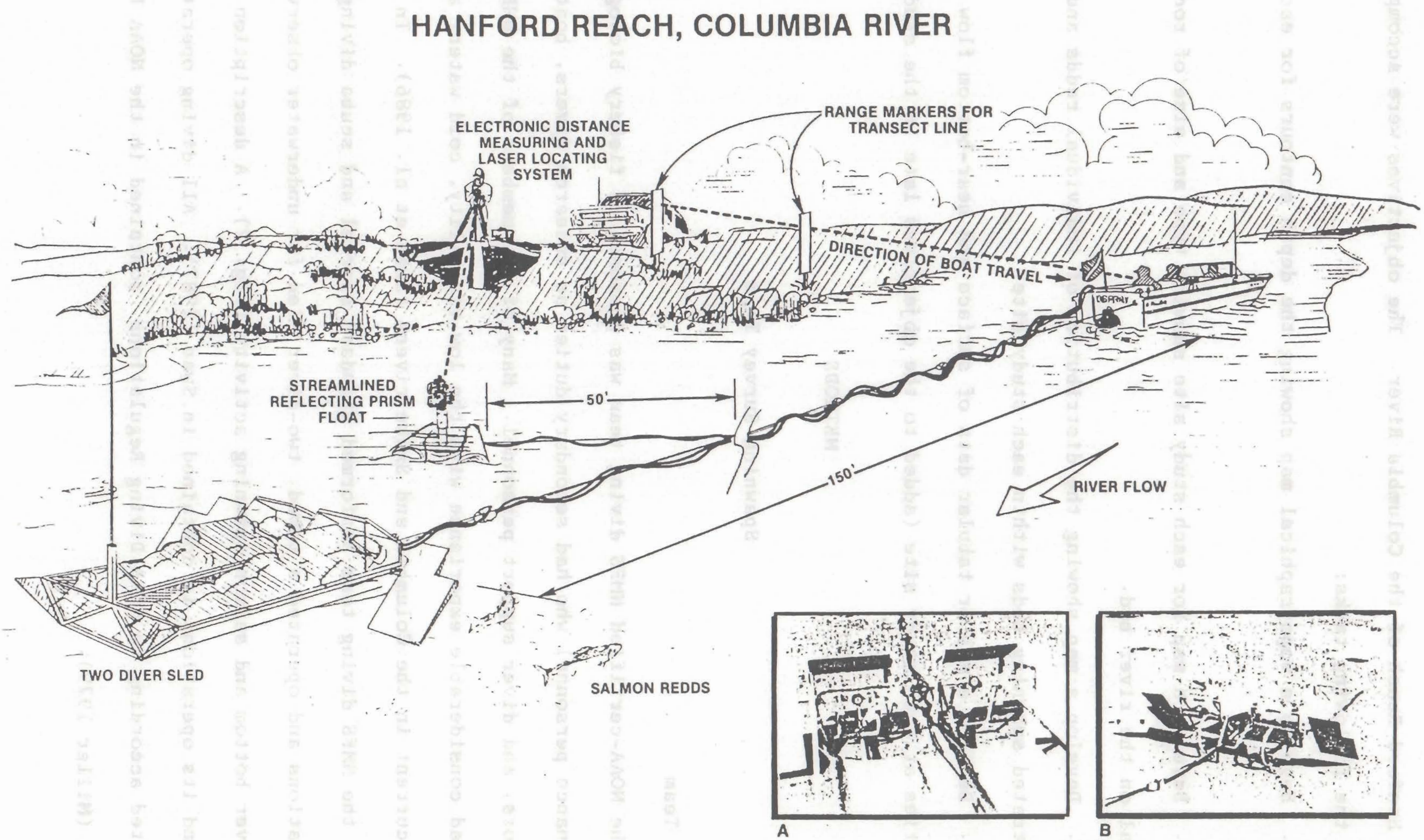

Figure 2.--Depiction of operational procedures during the 1986 deep-water survey of fall chinook salmon spawning in the Hanford Reach of the Columbia River. Inset A shows the "water shields" which deflect flow above and below the divers and the "flight controls" on the port side. Inset B is a front view of the two-diver sled and the tow line complete with communication and electronic cables.

Location and Mapping Team

The HDA surveying team was composed of engineers, surveyors, and technicians who operated the laser locating system, fathometer, electronic data recorder, mapping and surveying systems, and support equipment.

Spawning Survey Equipment

Support Equipment

The following support equipment was utilized during the spawning survey:

1. Aluminum, 21-ft, 165-hp inboard/outboard work boat (diver-sled towboat).
2. Inflatable 15-ft boat with 40-hp outboard motor (diver pickup boat).
3. Additional boats for depth mapping and transportation of personnel and equipment.
4. Vehicles (including one 4-wheel drive)for towing boat trailers.
5. Portable Marsh-McBirney[2] electromagnetic water current meters (one Model 201 mounted on the tow boat and one Model 511 mounted on the diver sled).
6. An Alpha Hydro-tracking EDM (electronic distance measurement) and Total Laser Surveying System (Hydro Link, produced by International Measurement Control Co. of Littleton, CO) for determining position.
7. A Raytheon-119D fathometer for depth sounding.
8. A laser reflecting prism attached to a streamlined surface float (floating about 5 ft in front of the diver-sled location) for determining position.
9. Portable radios for survey party communication.

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[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

10. Portable radios from Hanford Operations Security for emergency contact.

11. Portable "bull horn" loudspeaker, to ward off boaters approaching the survey area while divers were in the water.

Specialized Diving Equipment

In addition to standard scuba diving equipment for individual divers, the following specialized diving equipment was utilized:

1. Standard twin or double 50- or 80- ft^3 scuba tanks and backpack units.

2. AGA full-face dive-masks with built-in regulator and communication components.

3. Variable-volume dry diving suits with insulating undergarments.

4. A 30- to 40-lb lead weight belt per diver to maintain buoyancy control during high-velocity sled riding.

5. Underwater 35 mm Nikonos camera.

6. Sony 8 mm video camera and underwater housing.

7. A two-place diver-sled (Fig. 2) equipped with a hardwire communication system, current meter, temperature sensor, and a 150-ft towline (Swan 1987).

Preparations

An initial information gathering process included the following: 1) a literature search on salmon spawning (particularly, main-stem spawning in deeper water); 2) interviews with individuals who had personal experience and knowledge of salmon spawning in the Hanford Reach; and 3) coordination with personnel of Grant County PUD, who annually monitor salmon spawning on the Vernita Bar, and personnel of Battelle Northwest, who have conducted annual aerial surveys of salmon spawning on the Hanford Reach since 1947.

Preparations for the spawning survey began in August with full-scale planning and coordination of the NMFS dive team with the COE, HDA, and fishery agencies. Construction and testing of the diver sled was accomplished in August. During September, considerable time was spent allowing dive team members to become proficient at operation of the sled. In addition, specialized diving equipment was prepared and crew members were trained in its use in the Hanford Reach and other river environments. This training ensured that divers were at acceptable proficiency levels to perform the spawning survey in high velocities and deeper water (to 50 ft) littered with large boulders.

Due to budget and time constraints, it was impractical to consider a complete redd count throughout the 52 miles of the Hanford Reach. Therefore, the study focused on selected key sites. Study sites were selected after consultation with the various fishery agencies and private research organizations who have conducted spawning studies in shallow waters of the Hanford Reach. Segments of deep channels (determined from earlier depth profiles of the proposed barge channel) in the river near known sites of concentrated spawning in shallow water were selected. The sites varied in size from 1,000 to 2,000 ft (parallel to flow) of river channel length by the existing width (shore to shore). Personnel from HDA marked each site with a baseline on the most accessible shoreline. The baseline was established at 50-ft centers and correlated with the nearest pair of sounding range control stations. Figure 1 shows the study sites in the Hanford Reach by approximate river mile and designated site name.

Because much of the spawning survey took place within the confines of the Hanford Nuclear Project, special logistical arrangements were required. These included approval from the U.S. Department of Energy, Richland, Washington, to enter and leave with vehicles, boats, and survey and diving equipment and to launch and retrieve boats at several sites.

Early in September, HDA established the first 2,000-ft baseline on the right bank (facing downstream) of the Columbia River at the Midway Study Site (RM 391.8) (Fig. 1). This was for a trial redd mapping survey to test the proposed procedures and equipment. Range target stakes were set at 50-ft intervals to provide the NMFS boat operator with visual navigation references when making the cross-current transects during this trial survey. The Midway baseline was tied into existing traverses established by HDA for other work conducted for the COE. Minor adjustments of equipment and procedures took place through the latter half of September during and after the trial redd survey.

Survey Procedures

Once the hardware and equipment problems were resolved, HDA and the NMFS dive team completed development of the survey procedure. After several trial surveys at the Midway Site, the final equipment and operational procedures for deep-water salmon spawning surveys were established.

The following is a description of the standard operational procedure during the spawning survey (Fig. 2). The tow boat, towline, and diver-sled were made ready near shore at the upstream end of the study site. About a 3-ft minimum depth was required for operation of the boat and sled. After a safety check of all systems and the diver's equipment, the divers mounted the sled and plugged the wire connection from their full face masks to the hardwire telephone cable system. This allowed two-way communication between the divers and the tow boat.

When both divers were securely aboard the sled and ready, the control locks were disconnected and the tow boat was directed to proceed. Throughout the survey, the inflatable 15-ft chase boat maintained a position downstream and to the side of the diver sled to render assistance or retrieve the divers at the end of a survey.

Spawning surveys at each study site were accomplished by towing the diver sled on cross-current transects from shore to shore using the same 150-ft cross section intervals previously used by HDA to measure and map depth profiles. The tow-boat operator maintained alignment on two fluorescent range markers, one near shore and one farther back and at a higher elevation (Fig. 2). Approximately 12 cross-current transects, beginning at one river bank and terminating at the opposite bank, were made at most of the sites. The diver (pilot) riding the port side of the sled operated the controls. The diver (observer) riding the starboard side, described bottom materials and spawning activity to the boat crew. The pilot held the sled 3 to 5 ft above the river bottom for best visibility. As the tow boat traveled cross-current, the sled (trailing downstream) maintained an oblique angle to the current. On shore, the location and mapping team constantly monitored the coordinates of the dive sled by tracking the prism float, positioned on the surface and slightly upstream from the sled, with the laser locating system. Crew members in the tow boat maintained communications with the divers and the shore party and entered data regarding bottom materials and redd locations and abundance into the computer system for subsequent mapping. When the divers called out "redd," the crew member in the tow boat, operating the computerized laser location device, entered the information by pressing a single button which at that moment logged the coordinates of the prism float. In the event of concentrated, overlapping redds, the divers called out "redds begin" at the edge of the spawning bed and "redds end" when the sled left the spawning bed. This information was entered into the computer by rapid steady pressing of a location data entry button. All of the data entered into the computer system were backed up by handwritten notes taken by the crew member monitoring communications. Bottom times (duration of dive), water temperature, and current velocities were also recorded separately.

Upon reaching the opposite shore, the divers and sled surfaced. The boat and sled drifted 150 ft downstream, lined up on the new range markers, and a new transect began in the opposite direction. Each site was to be surveyed a minimum of three times between mid-October and late November to acquire early-, mid-, and late-spawning seasonal data. Table 1 lists the survey dates for each site.

During the trial survey, HDA and the NMFS diving team set the following criteria for describing bottom materials:

Type	Particle size
Sand	Loose particles to 2 in
Gravel	2 to 4 in
Rubble	4 to 8 in
Rock	8 to 12 in
Boulders	Greater than 12 in
Bed rock	Solid rock bottom

Following the trial survey and prior to the beginning of spawning, adequate time was available to conduct transects at each site to document the river bottom composition. The divers called out the transitions from bottom material of one particle size to another on each transect. At each point of transition, the laser system recorded the position and the operator noted the type of materials identified by the diver.

On 6 October, HDA mobilized two hydrographic survey teams to begin the bottom mapping for the five original salmon spawning survey sites selected by the NMFS research diving team. Typically, each site was about 2,000 ft long (parallel to the river flow) with marked baselines on shore for mapping procedures (developed in the trial survey). After the baselines were established, bathymetric mapping was accomplished using the Alpha Tracking EDM

Table 1.--Survey dates and series for fall chinook salmon spawning sites in the Hanford Reach of the Columbia River, 1986.

Survey date	Site
15 Oct	Locke Island
16 Oct	Hanford
17 Oct	Coyote Rapids
20 Oct	Vernita
21 Oct	Midway
22 Oct	Hanford
23 Oct	Hanford
23 Oct	Locke Island
26 Oct	Coyote Rapids
27 Oct	Hanford
28 Oct	Locke Island
29 Oct	Coyote Rapids
30 Oct	Midway
03 Nov	Vernita
04 Nov	Locke Island
06 Nov	Upper Hanford
07 Nov	Upper Locke
08 Nov	Vernita Bar
09 Nov	Vernita
10 Nov	Midway
11 Nov	Coyote Rapids
12 Nov	Hanford
12 Nov	Upper Hanford
13 Nov	Locke Island
13 Nov	Upper Locke
14 Nov	Vernita
16 Nov	Vernita Bar
17 Nov	Midway
18 Nov	Upper Hanford
19 Nov	Upper Locke
20 Nov	Midway
21 Nov	Vernita Bar

or Hydrolink Laser system. The 1 in = 50 ft scale, 1-ft interval contour bottom-mapping began with cross-sections profiled every 50 ft from the high water mark (vegetation line) bank to bank. The cross-section interval was later revised to 150-ft centers for the survey, with the exception of the Upper Locke Site (left at 50-ft intervals because of the site"s relatively short length), due to time/schedule considerations and later site changes. The five sites were mapped for bathymetry by 14 October, and the baselines were set and flagged by 15 October. These maps were used as the base for the bottom materials and redd location mapping.

Initial surveys suggested that substantial redd areas were being overlooked, so three more survey sites were added during the study (see Results Section).

Throughout the spawning survey, river flows were generally regulated at Priest Rapids Dam to a maximum 70 K ft^3/s during the daytime (0800-1600 h) when the surveys were actually conducted. Flows from 1700-0700 h ranged upwards to a maximum of 173 Kft^3/s. Figure 3 shows the high-, low-, and survey-flow (flow between 0800 and 1600 h) for each survey day. Table 2 lists the average daily water temperature, turbidity, and discharge at Priest Rapids Dam in October and November. Elevation of the river surface, in the upper end of the Hanford Reach, was substantially affected by discharge from the dam. This effect gradually diminished downstream to about the middle of the reach, where the river surface was nearly equal to the forebay level at McNary Dam near Umatilla, Oregon (Carlson[3]). The McNary reservoir extends from the dam (RM 292) to just upstream from Richland, Washington.

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[3]Chris Carlson, Grant County PUD, P.O. Box 878, Ephrata, WA 98823; pers. commun.

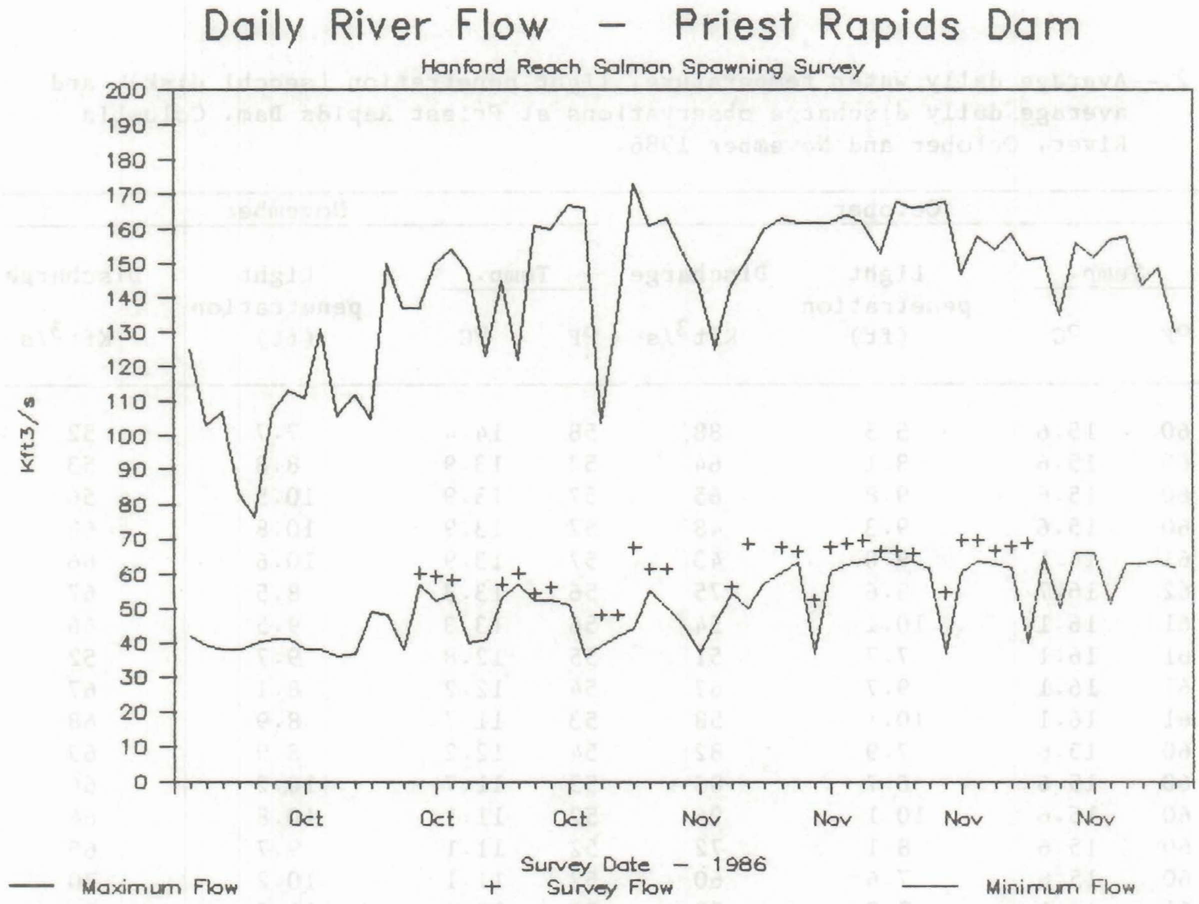

Figure 3.--River flow (Kft^3/s) at Priest Rapids Dam during the deep-water survey of fall chinook salmon spawning in the Hanford Reach of the Columbia River during October and November, 1986.

Table 2.--Average daily water temperature, light penetration (secchi disk), and average daily discharge observations at Priest Rapids Dam, Columbia River, October and November 1986.

Date	October				November			
	Temp.		Light penetration	Discharge	Temp.		Light penetration	Discharge
	°F	°C	(ft)	Kft^3/s	°F	°C	(ft)	Kft^3/s
01	60	15.6	5.5	88	58	14.4	7.7	52
02	60	15.6	8.1	64	57	13.9	8.8	53
03	60	15.6	9.8	65	57	13.9	10.5	56
04	60	15.6	9.3	48	57	13.9	10.8	68
05	61	16.1	9.0	43	57	13.9	10.6	66
06	62	16.7	9.6	75	56	13.3	8.5	67
07	61	16.1	10.1	54	56	13.3	9.5	66
08	61	16.1	7.7	51	55	12.8	9.7	52
09	61	16.1	9.7	67	54	12.2	8.1	67
10	61	16.1	10.1	58	53	11.7	8.9	68
11	60	15.6	7.9	82	54	12.2	8.9	69
12	60	15.6	6.7	83	53	11.7	10.2	66
13	60	15.6	10.1	96	52	11.1	10.8	66
14	60	15.6	8.1	72	52	11.1	9.7	65
15	60	15.6	7.6	60	52	11.1	10.2	70
16	61	16.1	7.3	59	51	10.6	11.0	54
17	61	16.1	8.3	58	50	10.0	10.2	69
18	61	16.1	8.3	58	50	10.0	10.2	69
19	61	16.1	10.1	42	51	10.6	10.4	66
20	60	15.6	8.4	57	51	10.6	10.2	67
21	59	15.0	7.5	60	51	10.6	12.7	68
22	60	15.6	10.1	54	51	10.6	9.9	70
23	60	15.6	10.0	56	51	10.6	8.1	62
24	60	15.6	12.2	55	51	10.6	7.7	70
25	60	15.6	11.6	49	51	10.6	10.6	69
26	60	15.6	10.8	48	50	10.0	9.7	67
27	60	15.6	6.4	48	50	10.0	9.8	71
28	60	15.6	10.9	67	50	10.0	7.9	68
29	59	15.0	8.6	61	49	9.4	7.5	68
30	58	14.4	8.6	61	49	9.4	7.5	68
31	58	14.4	8.2	67				

During the actual field survey, depths of redds were estimated by a diver's depth gauge mounted on the sled (always subject to some variation). However, after mapping the redds was completed, elevation of the redds, compared to the high water (vegetation line) elevation at each study site, provided a common baseline to calculate depths of redds.

RESULTS

Spawning Survey Activities

Spawning at Vernita Bar, the major spawning area in the Hanford Reach, began about 22 October (Dell[4]). Throughout the trial survey, which ended 26 September 1986, no redds were observed.

The actual spawning survey for redd mapping began on 15 October at the Locke Island Site (RM 374.2). River temperature was 60°F (15.6°C), and underwater visibility was about 7.5 ft (Table 2). Other surveys were conducted at the following locations: the Hanford Site (RM 367.6) on 16 October, the Coyote Rapids Site (RM 381.8) on 17 October, the Vernita Site (RM 394.0) on 20 October, and the Midway Site (RM 391.8) on 21 October (Table 1). Bottom materials were identified and mapped with no redd sightings. A map showing bottom materials, depths, and resulting spawning information for each study site is included in Appendix A. Data from each survey were reduced and plotted on work sheets at HDA's temporary Richland office to provide timely reviews of the data and contour maps of the river bottom for the divers.

The second series of surveys began with the Hanford Site on 22 October. Substantial numbers of adult salmon were observed in the study sites, but no true redds were discovered by the end of this series (26 October). However,

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[4]Mike Dell, Grant County PUD, P. O. Box 878, Ephrata, WA 98823; pers. commun.

areas that the divers termed "test holes" were located in areas of lower velocity where fish apparently had been moving the gravel, making circular depressions about 6 in deep and approximately 1-1.5 ft in diameter--so noted by the bright and clean condition (free of algae) of the area disturbed by the fish. Welsh, Fishery Consultant, McCall, Idaho, described "false redds" as initial egg pockets that had been abandoned by the female before egg deposition (Platts et al. 1983). The "test holes" we observed were similar to what Welsh described. However, the typical size, shape, and configuration of salmonid redds were not present. We made no observations of the fish actually digging these "test holes", therefore, we are unsure if they were made by salmon or another species. One more complete resurvey of the five sites was accomplished between 27 October and 3 November recording more "test holes" and a very small number of actual redds.

A member of the NMFS team accompanied Mr. Don Watson of Battelle Northwest on an aerial spawning-survey flight over the entire Hanford Reach on 1 November. The water surface and sunlight conditions were exceptionally favorable on that day. The aerial observers saw large numbers of redds in shallow water (disappearing into deeper water in many areas), especially in the vicinity of Vernita Bar and upstream from the Locke Island and Hanford sites. It was apparent there were large concentrations of redds outside of our survey sites. The redds observed from the air appeared to be concentrated upstream or downstream from three of our selected sites. For this reason, the researchers requested approval from the COE for the addition of three new survey sites--Upper Hanford (RM 369.0), Upper Locke Island (RM 375.5), and Vernita Bar (RM 392.8) (Fig. 1)-- for the redd mapping program. After conducting at least one more survey in each of the five original sites for verification of the lack of spawning activity, further surveys were discontinued at the Hanford, Locke Island, and Coyote Rapids sites.

HDA began setting baselines and bathymetric mapping for the three new sites on 4 November. Bathymetry and mapping for the new sites were completed on 9 November.

The spawning site surveys were resumed on 4 November. Spawning activity was increasing rapidly. The survey team began to find large concentrations of overlapping redds, in addition to individual redds, making it virtually impossible to enumerate each redd. Areas of concentrated spawning were portrayed on the redd maps by regularly spacing the symbol "o" for redds at 10-ft intervals at the scale of 1 in = 50 ft.

On 16 November, personnel from NMFS and HDA met at the Vernita Bar Site with representatives of Grant County PUD, Seattle District COE, and various fishery agencies who were conducting a ground count of redds during the very low water flows arranged for the occasion. Personnel from NMFS and HDA conducted a survey of deep-water redds in the Vernita Bar Site and provided a demonstration of the sled survey technique. Spawning in the Hanford Reach appeared to be at its peak. Water temperature had dropped to about 50°F (10°C) since the beginning of the surveys (Table 2). Turbidity remained favorable for diving, with 10-11 ft of visibility on survey days (Table 2).

Deep-water spawning surveys were continued through 21 November at the five productive survey sites. The NMFS and HDA completed field activities on 22 November.

Data were returned to HDA's Kirkland, Washington, office for a complete review and preparation of final mapping. On 19 December, HDA delivered the final products for the redd survey mapping program to the Seattle District COE. Included were one mylar bathymetric base map (1 in = 50 ft with 1-ft contours), a scale bottom materials map overlay (1 in =50 ft), and a scale redd mapping overlay (1 in = 50 ft) for each of the eight study sites. Reduced and combined copies of these maps are in Appendix A.

Survey Site Observations

Results of the surveys of the physical characteristics and the distribution and relative abundance of the mapped spawning activity in each study site are presented in this section. The maximum spawning depths, peak redd count dates, peak redd counts, and the total redd count for each site for the survey season are summarized in Table 3. Table 4 shows the estimated percent utilization of the substrate area in each survey site and the general appearance for spawning suitability when viewed from the surface. A summary of the information for each survey site is provided in Appendix B.

Hanford--RM 367.6

The Hanford Site was bordered by White Bluffs on the east bank (on the left, facing downstream) and the Hanford Works Project on the west bank. The western half of this site appeared suitable for spawning. The depth increased quickly from the vegetation line at 368 ft elevation (el.) to about 350 ft el. (18 ft deep) and remained at 10 ft out to about one-fourth of the river's width. From there to mid-river, the bottom sloped gently down to about 340 ft el. (28 ft deep). In contrast, the eastern third of this study site was virtually unsuitable for spawning habitat. The river bottom had a gentle slope from the vegetation line to 355 ft el. (13 ft deep) and was covered with sparse patches of very thin layers of sand and gravel over bedrock with scattered large boulders. From there to mid-river, the bottom was covered with a very jumbled band (about 400 ft wide) of long narrow ridges about 10 ft high running parallel

Table 3.--Redd counts observed at each study site during deep-water spawning surveys in the Hanford Reach of the Columbia River, 1986.

Survey site	River mile	Maximum redd depth (ft)	Peak date	Peak redd count	Total redd count
Hanford	376.6	--	--	0	0
Upper Hanford	369.0	10	12 Nov	66	98
Locke Island	374.2	15	28 Oct	5	5
Upper Locke Is.	375.5	25	19 Nov	180	267
Coyote Rapids	381.8	--	--	0	0
Midway	391.8	30	17 Nov	183	384
Vernita Bar	392.8	23	16 Nov	141	163
Vernita	394.0	22	9 Nov	88	217

Table 4.--Percent utilization by fall chinook salmon of total substrate area within spawning survey study sites in the Hanford Reach, Columbia River, compared to suitability of the substrate appearance.

Site	Area of river bottom (ft^2)	Substrate appearance	Percent utilized for spawning
Hanford	3,200,000	Suitable	0
Upper Hanford	1,260,000	Suitable	36
Locke Island	3,150,000	Suitable	<1
Upper Locke Island	945,000	Suitable	33
Coyote Rapids	2,520,000	Questionable	0
Midway	2,145,000	Unsuitable	23
Vernita Bar	1,170,000	Suitable	25
Vernita	3,150,000	Suitable	13

to the river flow. These narrow ridges were initially described as "very large boulders and bedrock" by the divers. Examination of samples of the "boulders and bedrock" obtained by the divers revealed a hard sedimentary material rather than actual hard rock.

The survey crew theorized that as the White Bluffs area was subjected to natural slow erosion by the river, large portions of the bluffs fell or slid into the river. The softer layers of the sedimentary materials probably washed away leaving remnants of the harder layers (the narrow underwater ridges encountered by the divers on the sled) oriented in line with the river flow. No redds were sighted in this study area throughout the survey.

Upper Hanford--RM 369.0

The Upper Hanford Site was located about 1.5 miles upstream from the Hanford site and was also bordered by White Bluffs and the Hanford Project. Topography of the bottom was generally smooth with no large obstacles. Compared to the other seven study sites, this site was relatively shallow, never exceeding 10 ft in depth, based on the vegetation line at 364 ft el.

The substrate was rubble, with a large area of rock situated at the western downstream end of the site. The eastern downstream tip was covered with gravel.

Virtually all spawning in this site was found in the eastern third. The peak count of 66 redds was observed on 12 November, and the total redd count was 98. Concentrated salmon spawning occupied approximately 36% of the study area, and spawning occurred primarily in rubble-sized (4-8 in) substrate to a depth of 10 ft.

Locke Island--RM 374.2

The Locke Island Site was located about 1 mile upstream from Locke Island on the east river channel between the eastern bank and an unnamed tear-drop shaped island about 1.5 miles long by 0.5 mile wide at the widest point. The upstream end of this island was about 0.5 mile below the upstream end of White Bluffs. The eastern third of the site had very large boulders and bedrock (similar to the Hanford site) and was unsuitable for spawning. The remainder of the site had a gradual slope from the western shoreline to the deepest channel, about 355 ft el. (approximately 24 ft deep), and the bottom was divided into two large areas, one area covered by rubble and another by gravel.

Only five redds were observed in this study area despite its apparent suitability for spawning (rubble and gravel bottom material, moderate depths, and adequate velocities).

Upper Locke Island--RM 375.5

The Upper Locke Island Site was located near the point where the upstream end of White Bluffs extends north and the river turns and flows in a southerly direction. The area surveyed spanned the north channel between the northern (left) bank and small narrow island (about 0.5 mile long). A small study area by comparison to all others; the 14 transects were conducted at 50-ft rather than 150-ft intervals.

Bottom materials in the southern half were primarily rock and rubble. Near the end of the surveying, we observed numerous salmon carcasses caught on large boulders in the deepest channel and on submerged woody debris wedged among the boulders. Much of the northern half of this site was unsuitable for spawning due to sand or large boulders. However, approximately 300 ft upstream from the boundary of the study site, spawning extended from shore to shore in shallower water.

On 19 November (peak count day), 180 redds were counted. The total redd count was 267. Approximately 80% of the redds observed were in depths of 5 to 15 ft, and the remainder were found at 15 to 25 ft. About 33% of the river bottom within this site was used for spawning, with spawning primarily in rubble-sized rock. Additional spawning in the shallow water along the south boundary of this study site (near the upstream end of the small island) was not reflected in the above redd counts. The water level in the area was generally too low during the daytime for the tow boat and diver sled to operate.

Coyote Rapids--RM 381.8

The Coyote Rapids Site was located about 0.5 mile downstream from the actual Coyote Rapids (a well known landmark). It was roughly centered on the upstream water intake of an inactive reactor site of the Hanford Works Project. The river ran west to east through this site, with the north side of the study area bordered by the Saddle Mountain National Wildlife Refuge. The southern half of this study site had such low flows that beds of water milfoil were established in the shallows; higher velocities were found in the northern half.

The northern shoreline (left bank) was composed of boulders that extended underwater from the vegetation line to about 355 ft el. (32 ft deep). Large sections of rock and rubble covered the remainder of the northern half of the river bottom. The deepest channel and the majority of the river flow were also in this portion of the site. A meandering strip of boulders covered much of the central area south of the centerline of the river. The southern side contained a large area of sand near shore, an adjacent area of gravel toward mid-stream at the upstream end, and a section of rock which changed to rubble at the downstream end of the site.

The southern two-thirds of this site had substrate which appeared to be suitable for spawning, and salmon were observed in the site. However, there was no indication of spawning activity throughout the survey.

Midway--RM 391.8

The Midway Site was located about halfway between Priest Rapids Dam and the Vernita Bridge (Fig. 1). The site was so designated because of the Bonneville Power Administration's Midway Substation is located about 1 mile southeast of this study site. Power lines from the substation crossed the river a short distance downstream from the site.

Bottom materials in this study site were primarily rubble, with large areas of rock near each shoreline and a strip of gravel about 200 ft wide just parallel to and north of the centerline of the river. The bottom material at this site appeared to be the result of erosion of rubble and rock from Vernita Bar located about 0.5 mile upstream.

Redds were found at depths to 30 ft; however, most of the spawning was in a large area of rubble-sized substrate near mid-river at depths between 20 and 25 ft. Although the site appeared to be unsuitable based on visual surface characteristics and gave no indication of spawning activity along the shorelines, it yielded the highest total number of redds of all sites (Table 3). The most salmon observed at any deep-water survey site were at Midway on 17 November, the peak redd count day, when a total of 182 redds were counted. The total redd count for all surveys at Midway Site was 384. This study site was an excellent example of deep-water spawning in the main-stem river. Aerial observations of the shorelines gave no indication of any spawning activity. The river bottom sloped sharply from the vegetation line on both shorelines to a depth of about 20 ft. The middle half of the river channel was basically flat, reaching a maximum depth of about 30 ft.

Vernita Bar--RM 392.8

The Vernita Bar Site was located slightly upstream from the mouth of the side channel on Vernita Bar, which showed at lower river flows. The river bottom was composed primarily of rubble and a few scattered boulders, with the exception of a narrow strip of rock running the length of the site near the south shore and another sizeable patch of rock in the northern downstream end. The central portion of the downstream end of the site (approximately 1,800 ft^2) was gravel. Unless the discharge from Priest Rapids Dam was at high level (70 Kcfs or greater), the majority of the flow passed through the narrow and relatively shallow stretch at the south side of Vernita Bar. The depth increased sharply to about 20 ft off the downstream end of the main bar. The river bottom in mid-channel was fairly flat.

Concentrated spawning was confined to an area approximately 1,950 ft long and 150 ft wide (about 292,500 ft^2) which began at a point about 300 ft upstream from the mouth of the side channel on Vernita Bar and extended downstream. Approximately 70% of the concentrated spawning was between 10 and 15 ft deep; the remainder extended to 23 ft deep. All but 2 of the 140 redds counted on the peak count day, 16 November, were found in rubble-sized substrate. The total redd count for the surveys was 163.

Vernita--RM 394.0

The Vernita Site was located just upstream from Vernita Bar. River bottom materials at this site were predominantly rubble and rock with randomly interspaced large patches of gravel. Boulders (>12 in) bordered the upstream southern shoreline. The north bank sloped steeply underwater from the vegetation line to about 390 ft el. (about 7 ft deep) whereas the south shoreline (right bank) dropped quickly (within 100 ft) to 380 ft el. (about 27 ft deep). A gradual slope from the shallower north side of the river extended across the river bottom to the south. A channel of deeper water with elevations ranging from 376 to 367 ft (33 to 40 ft in depth) ran lengthwise through the southern third of the site.

Concentrated spawning was confined to a strip about 9 acres or 13% of the site, with redds observed to depths of 22 ft, but most being found in water 10-15 ft deep. The peak count of 88 redds was observed on 9 November with a total redd count of 217. This strip of spawning habitat was oriented in line with the river flow and was situated just north of the centerline of the river. It appeared to be an underwater extension of the upstream end of Vernita Bar. Most of the redds observed were on rubble- or rock-sized substrate.

DISCUSSION

Our direct underwater observations conducted with the diver-sled indicated that a substantial amount of deep-water spawning (>15 ft) by fall chinook salmon was occurring in the Hanford Reach of the Columbia River. Our findings for the occurrence of deep-water spawning were comparable with previous surface or aerial observations by Chapman (1943), Chambers (1955), Meekin (1967), and Chapman et al. (1983). Bauersfeld (1978) also observed redds in deep water adjacent to Vernita Bar, but did not attempt to determine the depth distribution. He considered the possibility that some redds were constructed in water too deep to be seen during aerial surveys, but concluded that this was not likely since two of his surveys were conducted during minimum flow (36 Kcfs) and optimum viewing conditions.

Chapman et al. (1983), verified that a large portion of spawning extended below depths visible from boat or aircraft. Watson (1970 and 1976), who has conducted aerial spawning surveys over the Hanford Reach since 1947, pointed out shallow areas of spawning that appeared to continue into deeper water at three sites (Upper Locke Island Site, RM 375.5; Vernita Bar Site, RM 392.8; and Vernita Site, RM 394.0) to a NMFS observer during a survey flight. When surveyed a few days later with the diver-sled, there was indeed spawning activity too deep to be detected from the air at all three sites.

From redd maps superimposed over depth contour maps, we found spawning to 30 ft with an average maximum depth of spawning at 21 ft based on the high water elevation (vegetation line) at the five study sites where spawning was observed.

Chapman et al. (1983) suspected topography or morphology of the river bottom may be a major factor in the utilization of deep water spawning due to resultant downstream effect of flows/velocities created by upstream bottom morphology. They also determined that the redds and size of spawning substrate materials were much larger and velocities were higher at Vernita Bar than found by researchers studying salmon spawning in tributaries or smaller streams at other locations. Their study found no evidence that the size of redds observed in different elevation zones varied greatly, whether continually covered by water (deep spawning) or temporarily exposed part of the time above the wetted channel by lower flows (shallow spawning). They suggested that these observations might be related to the relatively large size of upriver bright fall chinook salmon. Based on our limited observations throughout the Hanford Reach, we concur.

Spawning occurred in five of the eight study sites in our survey. Virtually no spawning was detected in the remaining three sites. However, the requirements for salmon spawning (i.e., suitable current velocity and substrate appeared to be present.

We wish to emphasize that our objective was not to determine overall redd density, but to simply map the distribution and relative abundance of redds in the deep water of representative study sites. However, an attempt is made below to estimate redd density in each study site. In their Vernita Bar study, Chapman et al. (1983), by ground counts and with the aid of surveyors and actual mapping, determined a density of about 80 redds per acre in a 100-ft wide corridor along the 36 Kft^3/s flow line on the Vernita Bar. Welsh (1983) proposed that if divers could delineate the outer boundaries of the spawning area, and then establish the average redd size, the number of redds could be crudely calculated. Our redd mapping technique delineated the outer boundaries of the spawning areas with reasonable accuracy. We made no measurements of redd size. However, Chapman et al. (1983) measured 262 redds at Vernita Bar and found the average to be 183 ft^2. Therefore, based on Chapman's average redd size and our measurements of concentrated spawning area within each study site and using Welsh's method for calculating abundance of redds, we arrived at estimates of redd abundance and density in the five study sites where spawning occurred (Table 5).

Welsh's method of estimating abundance of redds appears to provide a reasonable estimate (an overall average of 242 redds per acre), but assumes that

Table 5.--Estimated redd abundance and density within concentrated areas of spawning in the five study sites where spawning was detected during the deep-water spawning survey in the Hanford Reach, Columbia River, 1986 [based on Welsh's methodin Platts et al. (1983)]

Survey site	Area (ft^2)	Acres[a]	Total redds[b] (estimated)	Redds/acre in concentrated spawning area (estimated)
Upper Hanford	450,000	10	2,459	246
Upper Locke Is.	315,000	7	1,721	246
Midway	487,500	11	2,664	242
Vernita Bar	292,500	7	1,598	228
Vernita	400,000	9	2,186	243
Grand total	1,945,000	44	10,628	Grand average 242

[a] One acre = 43,560 ft^2

[b] Average area of redd = 183 ft^2 (Chapman et al. 1983).

the spawning area is completely covered with redds with no allowance for spaces between redds.

Table 6 contains our extrapolations for redd densities in each study site in which spawning occurred, with an overall average of 113 redds per acre. As an alternative to Welsh's method, we calculated redd abundance and densities by determining the average number of redds observed by divers per transect line and multiplying this figure by the number of 15-ft increments (estimated to be a conservatively acceptable average underwater field of observation of the divers during this survey) contained in the length (parallel to river flow) of each site, providing estimated total redds, which when divided by the number of acres in the concentrated spawning area provided the number of redds per acre. Light penetration from the surface ranged from 6.4 to 10.9 ft with an average of 8.7 ft from 15 to 30 October. However, between 3 and 21 November (when all peak redd count days occurred) light penetration averaged 10 ft, with a range of 8.1 to 12.7 ft. We make no judgement as to the level of accuracy for the above methods for calculating redd density per acre.

We stress that the reader exercise caution in using either figure (113 or 242) for redd density. These data are based on field observations conducted on 150-ft transect intervals and assume a homogenous distribution of redds within the boundaries of the concentrated spawning area. Although these data represent the only known attempt to estimate deep-water spawning by salmon in segments of the Hanford Reach of the main-stem Columbia River, they should be regarded only as a rough baseline estimate. We feel the sled methodology for gathering the data is sound, but any future efforts to determine redd density and abundance in deep water should be preceded by more intense surveys of sample sites to verify efficiency of the technique and establish confidence in expansion factors.

Table 6.--Estimated density of redds for the area of concentrated spawning within each study site surveyed for deep-water spawning in the Hanford Reach, Columbia River, 1986.

Survey site	Peak redd count date	Transect lines	Redd count (site)	Redds/ transect	Length of[a] spawning area (ft)	Total redds[b] (estimated)	Concentrated spawning area (acres)	Redds/acre in concentrated spawning area (estimated)
Hanford	no spawning	14	--	--	--	--	--	--
Upper Hanford	12 Nov	7	66	9	900	540	10	54
Locke Island	no spawning	14	--	--	--	--	--	--
Upper Locke Is.	19 Nov	13[c]	180	14	700	653	7	94
Coyote Rapids	no spawning	14	--	--	--	--	--	--
Midway	17 Nov	14	182	13	1,950	1,690	11	154
Vernita Bar	16 Nov	14	140	10	1,950	1,300	7	186
Vernita	9 Nov	14	88	6	2,000	800	9	89
Grand total			656	10	7,500	4,983	44 Grand average	113

[a] Length of a study site was oriented parallel to the direction of main river flow.

[b] Estimated redds were calculated by dividing the length of the survey site by 15 ft (estimated field of visual observation of divers) and multiplying that quotient by the average number of redds per transect line.

[c] Transect numbers 13 and 14 for this site revealed no redds, therefore, only 13 transects were used for this estimate of redds within the boundaries of concentrated spawning.

A comparison of data shown in Tables 7 and 8 illustrates an additional concern for presenting and/or interpreting spawning data. By our method of calculation, concentrated spawning areas provided an average redd density of 113 redds per acre (Table 6); however, estimated average redd density for the total area within the five sites was only 26 redds per acre (Table 7). Comparing the total area of concentrated spawning to the total overall area of the study sites, shows that only an estimated 22% of the river bottom, within the five study sites where spawning occurred, was utilized for spawning (Table 8). Because the Hanford Reach exhibits considerable variety in riverine habitat (flows, velocities, substrate materials, and depths), extrapolation of data for any study site to the entire Hanford Reach, or only to segments with suitable appearing habitat, would surely result in questionable accuracy. Again, more thorough surveys are required.

SUMMARY AND CONCLUSIONS

1. The modified two-diver sled proved to be a highly effective device for making observations in a high-velocity river environment. The sled allowed divers to effectively observe salmon spawning activity and the physical characteristics of the river bottom.
2. The computerized data collected during the survey were translated into overlaying maps depicting substrate materials, depth contours, location of redds (when there was spawning), and boundaries of concentrated spawning for each of the eight study sites surveyed (Appendix B).
3. Deep-water redds (>15 ft) were observed at most of the sites where spawning was occurring (4 of 5 sites). Most deep-water redds were found at

Table 7.--Estimated density of redds in study sites surveyed for deep-water spawning in the Hanford Reach, Columbia River, 1986.

Survey site	Peak redd count date	Transect lines	Redd count	Redds/ transect	Length of[a] survey site (ft)	Total redds[b] (estimated)	Area of study site (acres)	Redds/acre for entire study site (estimated)
Hanford	no spawning	14	--	--	--	--	--	--
Upper Hanford	12 Nov	7	66	9	1,050	630	29	22
Locke Island	no spawning	14	--	--	--	--	--	--
Upper Locke Is.	19 Nov	14	180	13	900	780	22	35
Coyote Rapids	no spawning	14	--	--	--	--	--	--
Midway	17 Nov	14	182	13	1,950	1,690	49	34
Vernita Bar	16 Nov	14	140	10	1,950	1,301	27	48
Vernita	9 Nov	14	88	6	2,100	840	72	12
Grand total			656	10	7,950	5,241	199	Grand average 26

[a] Length of a study site was oriented parallel to the direction of main river flow.

[b] Estimated redds were calculated by dividing the length of the survey site by 15 ft (estimated field of visual observation of divers) and multiplying that quotient by the average number of redds per transect line.

Table 8.--Spawning utilization of total area (in acres) of study sites where spawning by upriver bright fall chinook salmon was detected during the deep-water spawning survey in the Hanford Reach, Columbia River 1986.

Survey site	Total area (acres)[a]	Concentrated spawning area (acres)		Utilization (%)
Upper Hanford	29	10		34
Upper Locke	22	7		32
Midway	49	11		22
Vernita Bar	27	7		26
Vernita	72	9		13
Grand total	199	44	Grand average	22

[a] One acre = 43,560 ft^2

the Midway and Vernita Sites at river velocities between 2.0 and 2.5 ft/s. Depth of deep-water spawning averaged 21 ft, with a maximum of 30 ft.

4. As observed from the surface or aircraft, the physical features of river segments, such as shoreline rock material and surface velocities, can be misleading as to their suitability for fall chinook salmon spawning in deep water. Observations of spawning ranged from none to many in areas of near identical observed physical characteristics.

5. A more comprehensive spawning survey with an increased number of transects would be required to accurately estimate deep-water spawning throughout the Hanford Reach.

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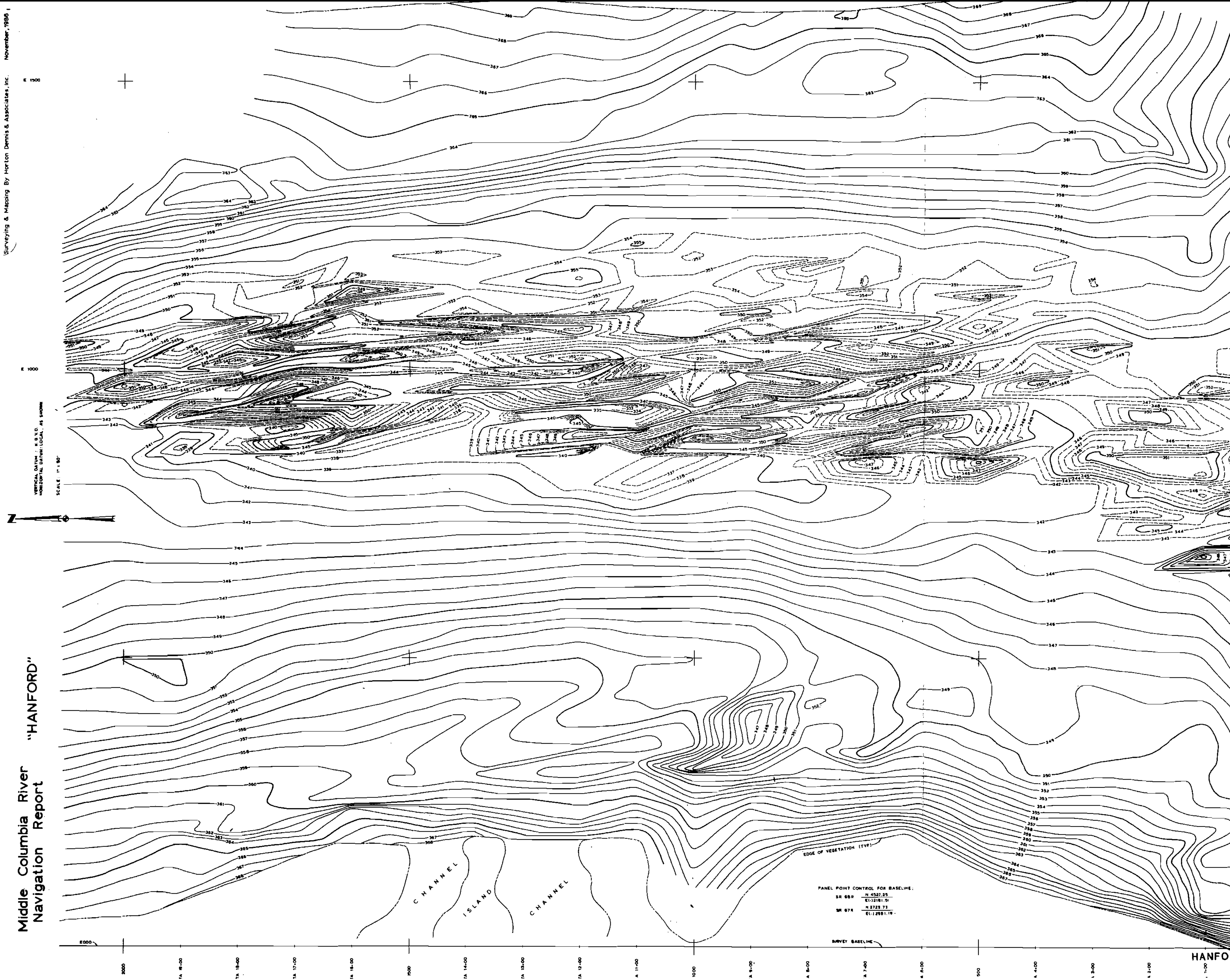
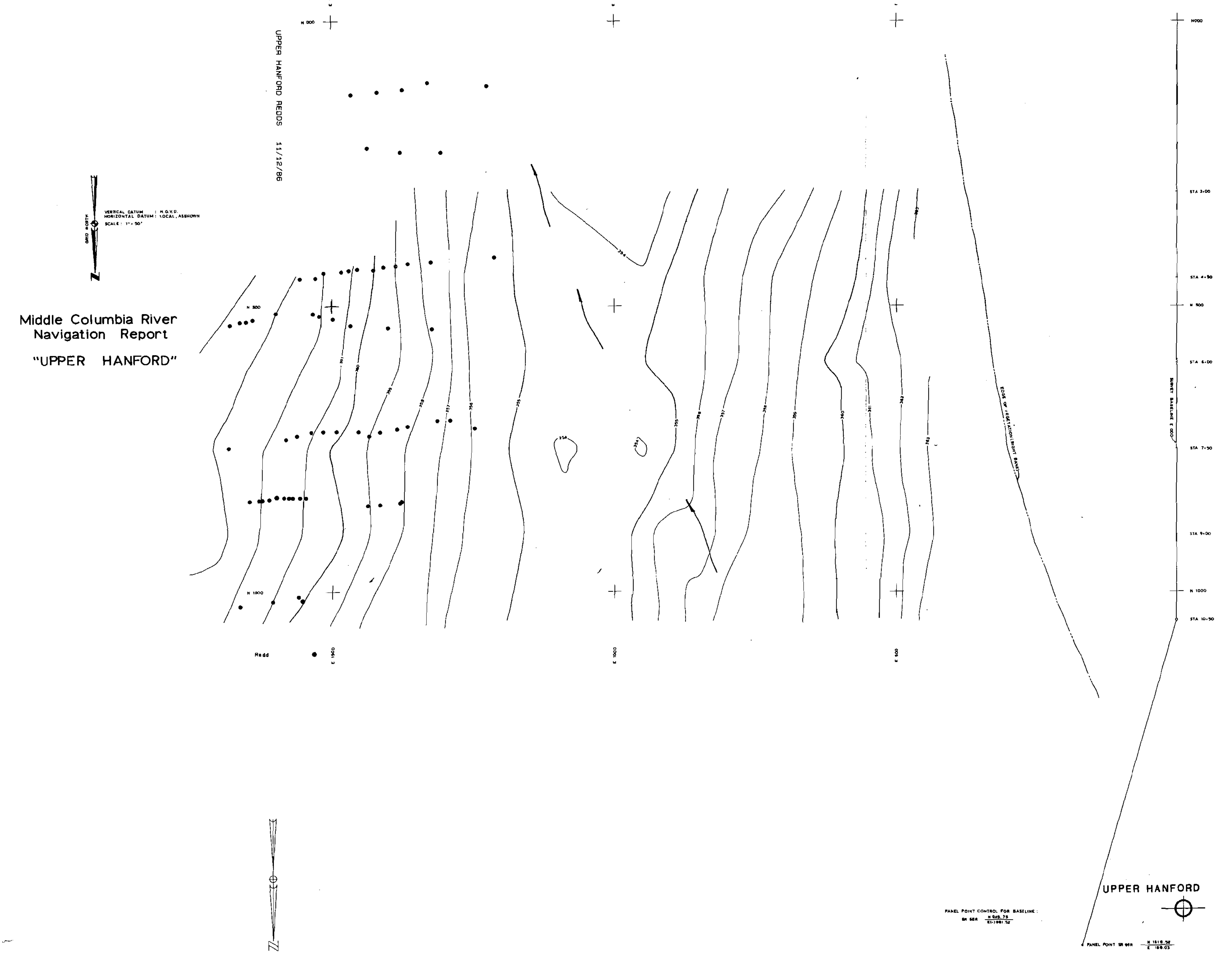
APPENDIX A

Maps for Each Study Site

Maps for Each Study Site



Middle Columbia River Navigation Report "HANFORD"

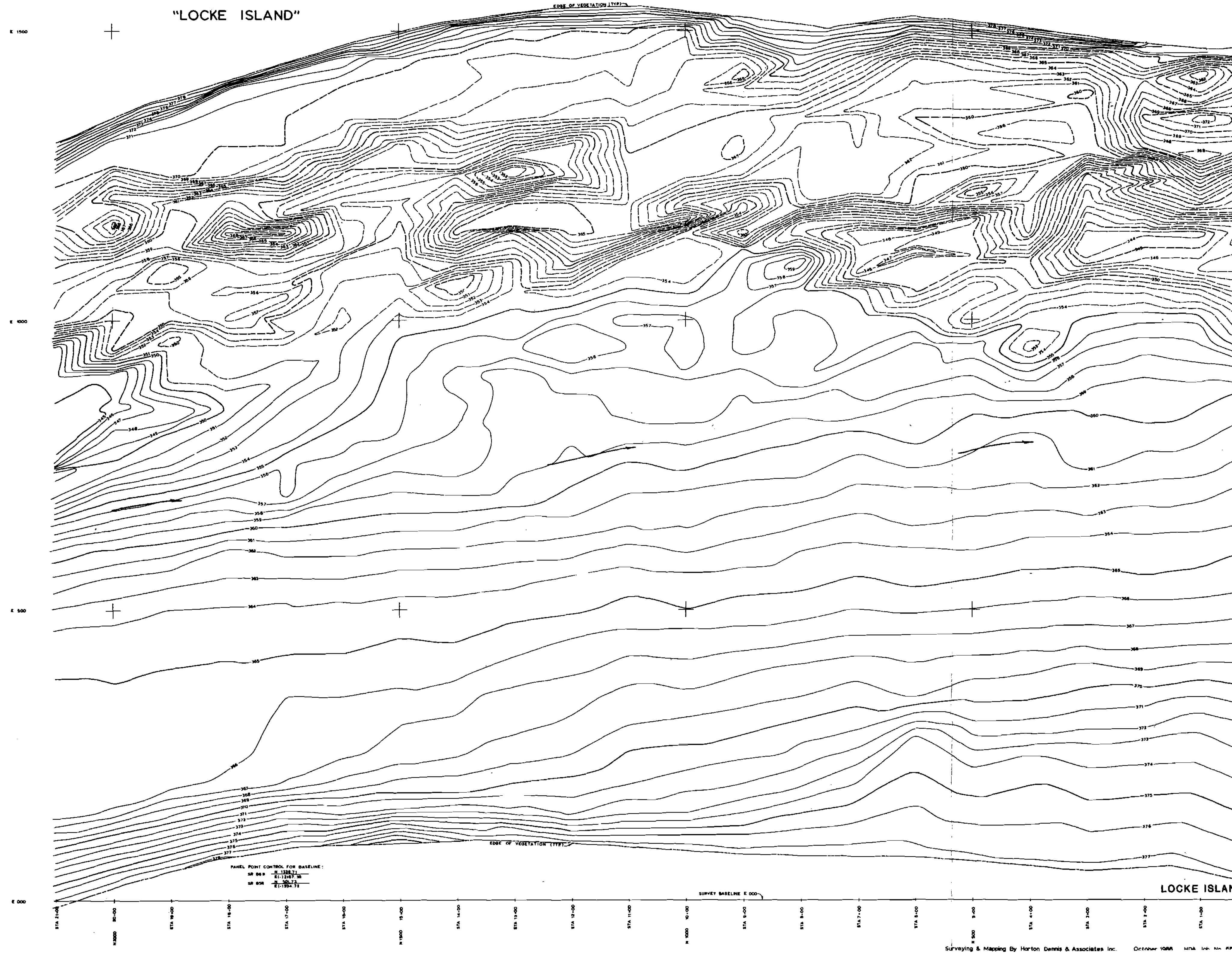


Middle Columbia River
Navigation Report
"UPPER HANFORD"
UPPER HANFORD REDDS 11/12/86
GRID NORTH
VERTICAL DATUM : N.G.V.D.
HORIZONTAL DATUM : LOCAL, AS SHOWN
SCALE : 1" = 50'
Redd
N 000
N 500
N 1000
E 1500
E 1000
E 500
354
355
356
357
358
359
360
361
362
363
EDGE OF VEGETATION (RIGHT BANK)
SURVEY BASELINE E 000
STA 3+00
STA 4+50
STA 6+00
STA 7+50
STA 9+00
STA 10+50
PANEL POINT CONTROL FOR BASELINE :
UPPER HANFORD

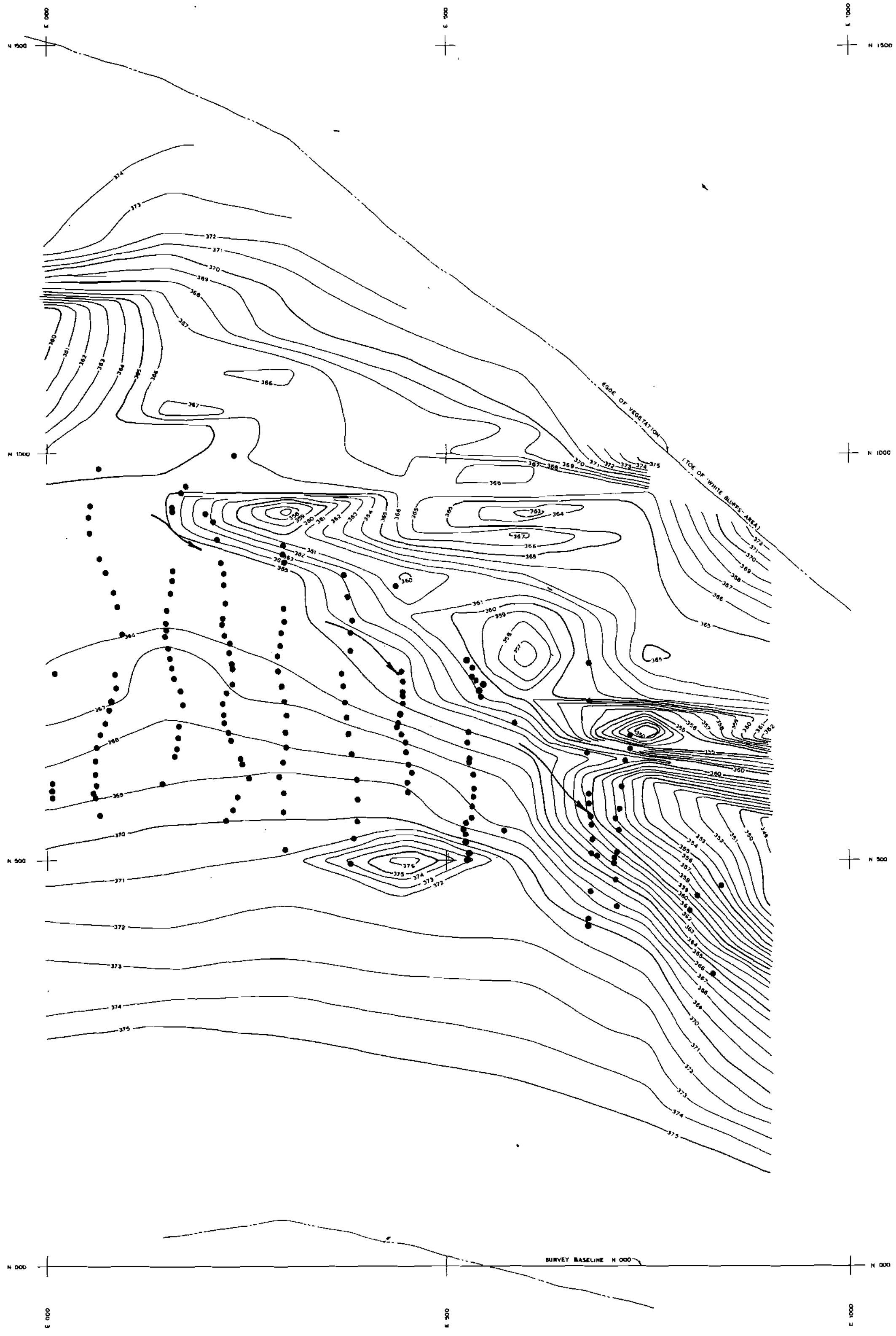
Navigation Report
"LOCKE ISLAND"

Scale: 1"=50'

Vertical Datum: N.G.V.D
Horizontal Datum: Local, As Shown



Surveying & Mapping By Horton Dennis & Associates Inc. October 1988 HDA Job No.



Middle Columbia River
Navigation Report
"UPPER LOCKE ISLAND"

VERTICAL DATUM . N.G.V.D.
HORIZONTAL DATUM . LOCAL, AS SHOWN
SCALE : 1" = 50'

UPPER LOCKE ISLAND REDDS 11/19/86

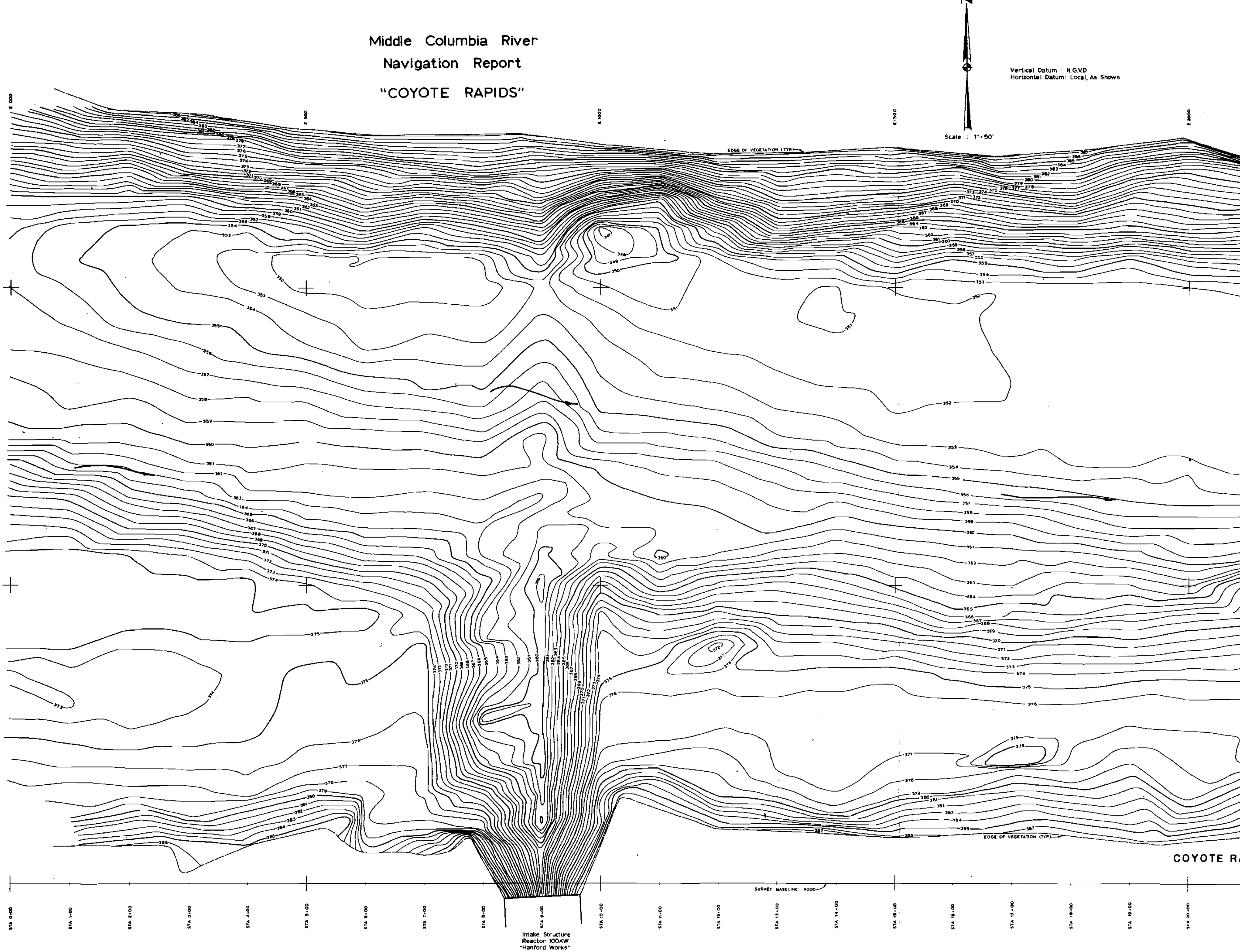
PANEL POINT CONTROL FOR BASELINE :

SR 92# N(-) 1131.05 / E(-) 3770.81

SR 66 R N(-)2391.14 / E(-) 1844.24

UPPER LOCKE ISLAND

Middle Columbia River
Navigation Report
"COYOTE RAPIDS"



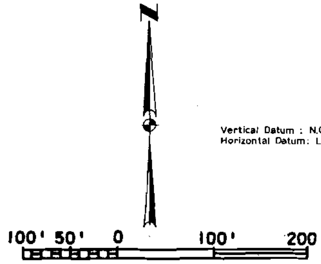
PANEL POINT CONTROL FOR BASELINE :
SR 106R N(-) 391.93 / E(-) 838.26
SR 105R N(-) 252.46 / E 053.91

Surveying & Mapping By Horton Dennis & Associates, Inc. October ,1986 HDA Job N

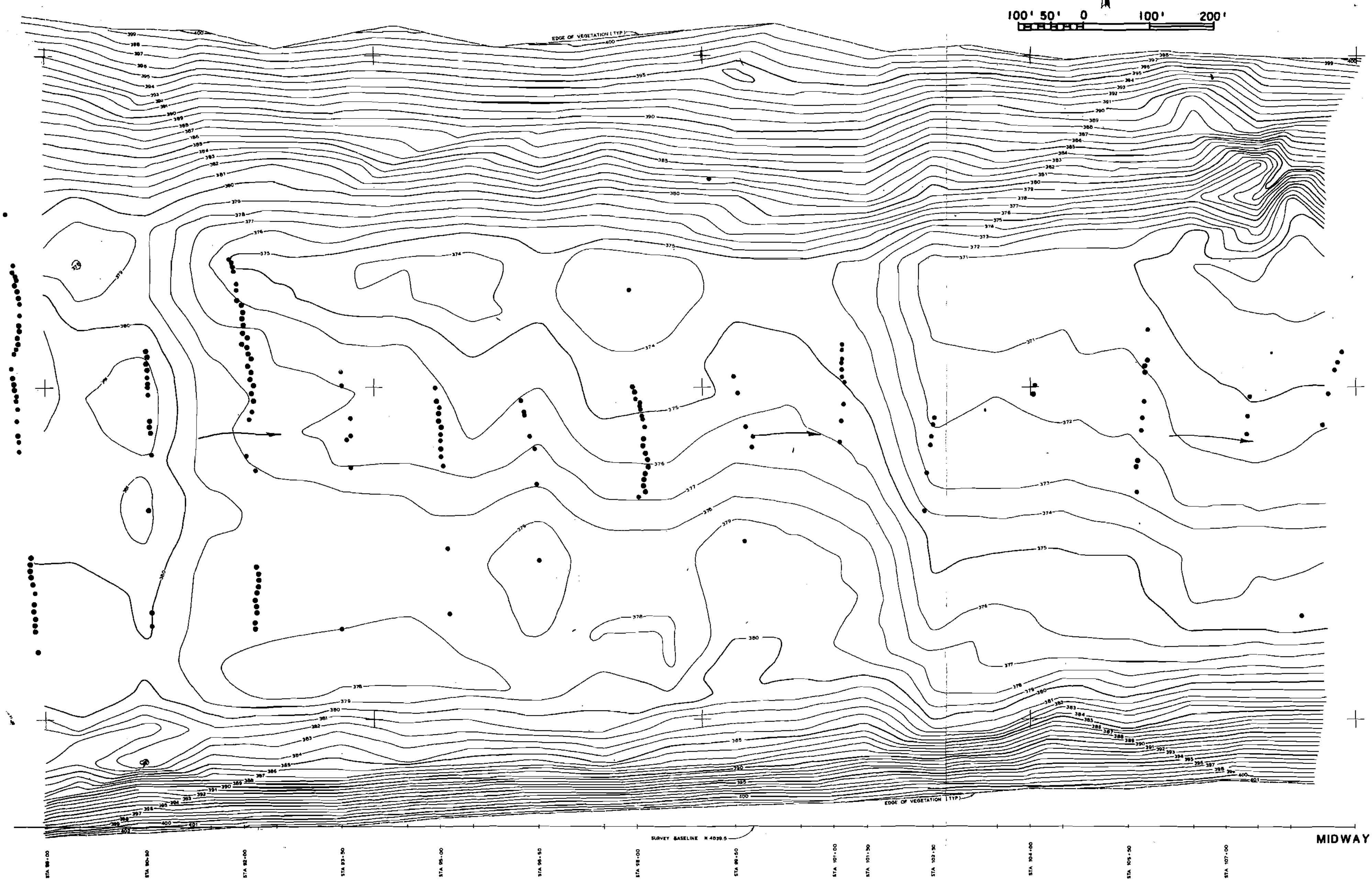
Middle Columbia River
Navigation Report
"MIDWAY"

PANEL POINT CONTROL FOR BASELINE:

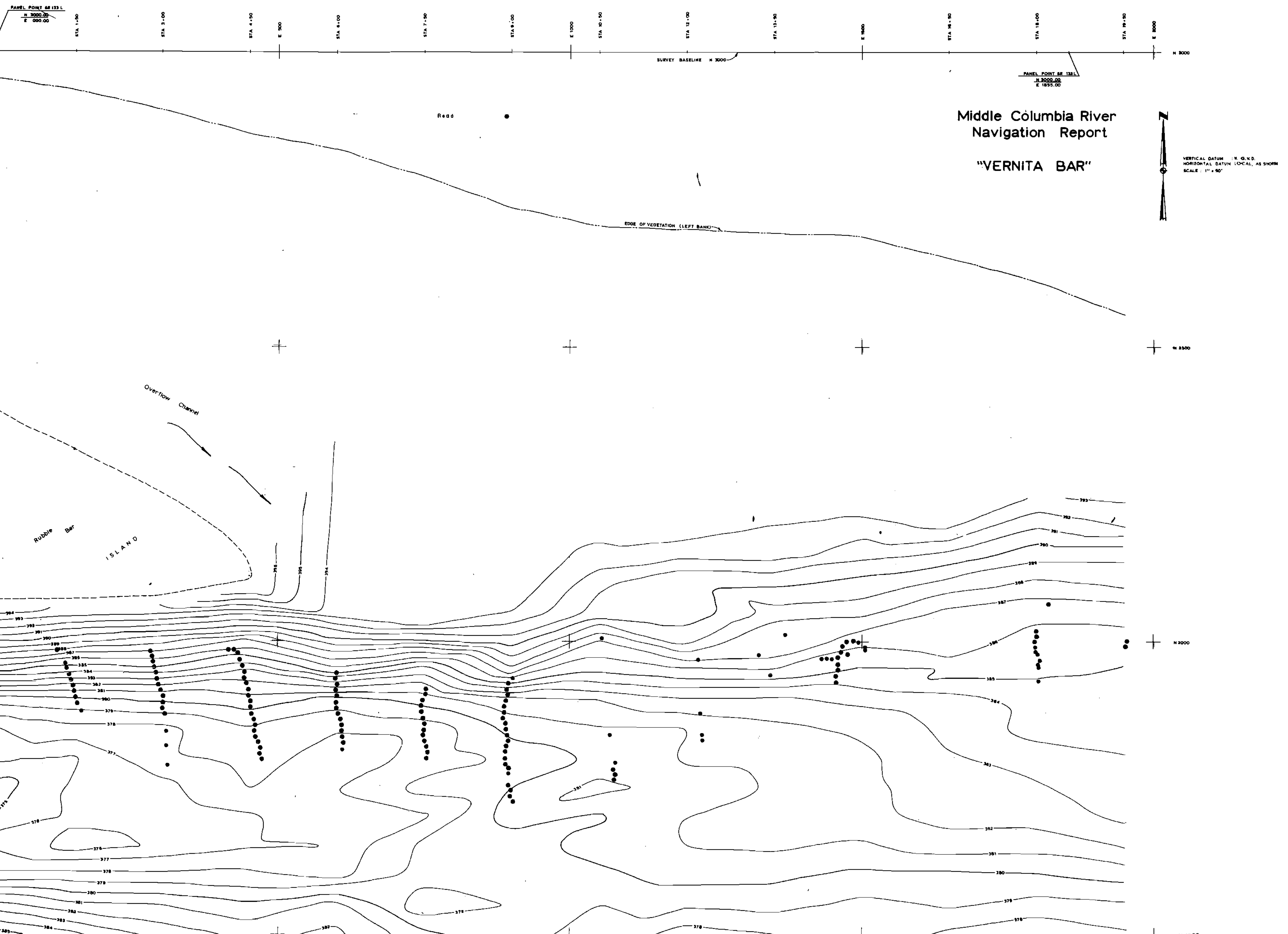
REDD	N 4066.19 / E 9934.82
SR 130L	N 6084.33 / E 10,663.86
SR 131L	N 6267.71 / E 9047.25
130.5L	N 6185.53 / E 9843.78



Vertical Datum : N.G.V.D.
Horizontal Datum: Local, As Shown

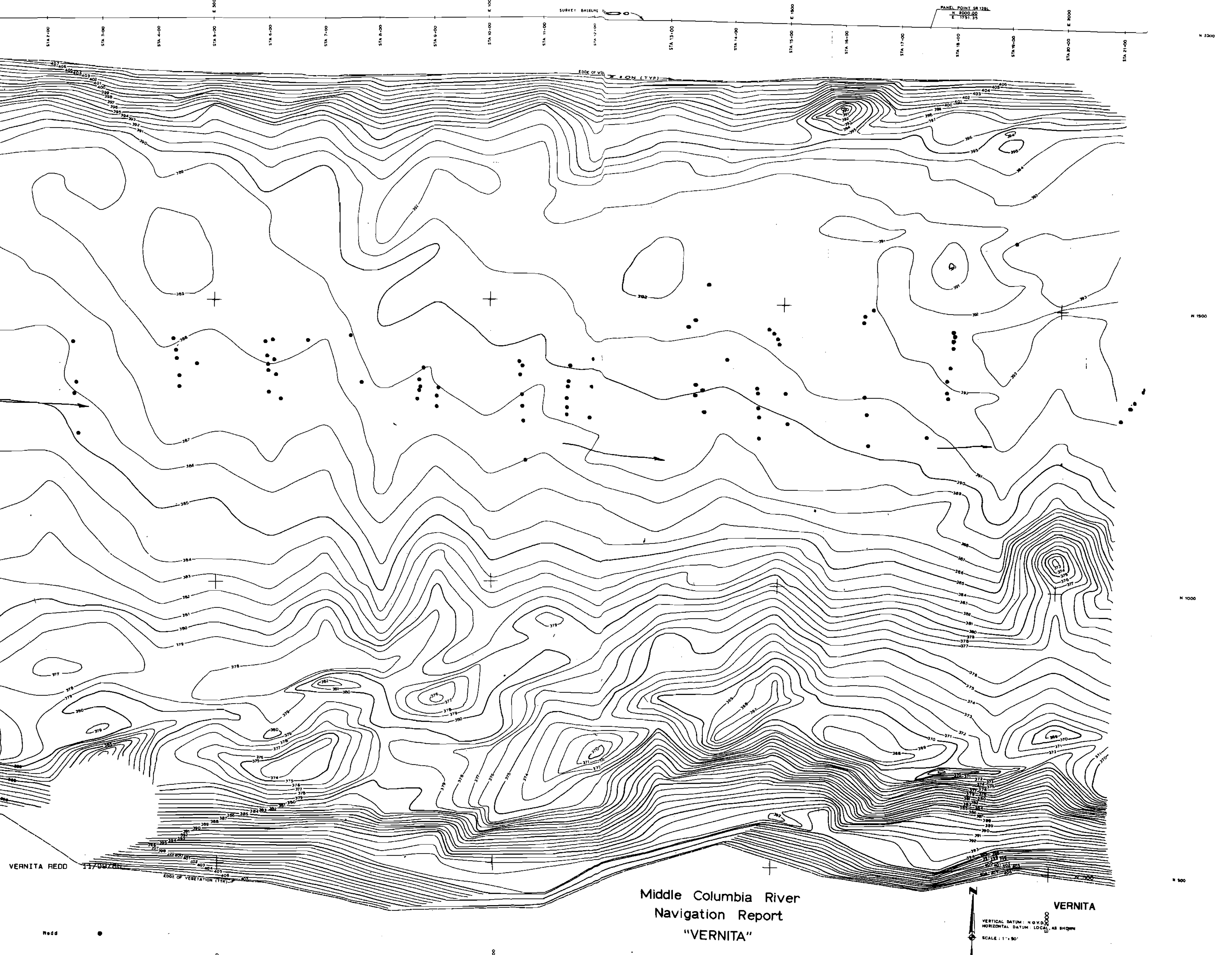


Surveying & Mapping By Horton Dennis & Associates, Inc. October, 1986 HDA Job No. 5594.6



Middle Columbia River
Navigation Report
"VERNITA BAR"
VERTICAL DATUM : N.G.V.D.
HORIZONTAL DATUM LOCAL, AS SHOWN
SCALE : 1" = 50'
SURVEY BASELINE N 3000
EDGE OF VEGETATION (LEFT BANK)
Redd
Overflow Channel
Rubble Bar
ISLAND
PANEL POINT 68 133 L
N 3000.00
E 000.00
PANEL POINT 68 133 L
N 3000.00
E 1895.00
STA 1+50
STA 3+00
STA 4+50
STA 6+00
STA 7+50
STA 9+00
STA 10+50
STA 12+00
STA 13+50
STA 15+00
STA 16+50
STA 18+00
STA 19+50
E 500
E 1000
E 1500
E 2000
N 3000
N 2500
N 2000

VERNITA BAR



Middle Columbia River
Navigation Report
"VERNITA"

APPENDIX B

General Descriptions and Summarized Information
for Sites Surveyed in the Hanford Reach, Columbia River, 1986

Hanford Site--RM 367.6

Miles below Priest Rapids Dam:	29.4.
Dimensions:	Approx. 2,000 ft long X 1,600 ft wide (3,200,000 ft^2 or 73 acres).
Maximum depth:	35 ft, based on the vegetation line (higher water mark) 368 ft el.
River bottom materials:	Western half - gravel (2-4 in) and rubble (4-8 in) appeared suitable for spawning. Eastern half - very large rocks and ridges - unsuitable for spawning.
Velocities (range):	Surface: 1.0 - 6.8 ft/s. Near Bottom: 4.0 - 8.0 ft/s.
Dates surveyed:	16, 22, 23, and 27 Oct and 12 Nov 1986.
No. transect lines:	14, (150-ft intervals).
Spawning:	None observed.
Remarks:	1. Abandoned survey of this site on 12 Nov. 2. On 12 November, special current-velocity readings were taken with the boat stationary, the sled on the bottom (depth varied), and the discharge from Priest Rapids Dam at 64 Kft^3/s.

Location within survey site	Location within water column	Approximate depth range (ft)	Velocity (ft/s)
Upstream end	Surface		5.6
	Near bottom	7-25	6.2
Middle	Surface		5.2
	Near bottom	14-24	5.3
Downstream end	Surface		5.4
	Near bottom	12-27	6.3

Upper Hanford Site--RM 369.0

Miles below Priest Rapids Dam: 28.0.

Dimensions:	Approx. 1,050 ft long X 1,200 ft wide (1,260,000 ft^2 or 29 acres).
Maximum depth:	About 10 ft at deepest point measured, based on vegetation line of 364 ft el.
River bottom materials:	By area, about 80% rubble (4-8 in) 18% rock (8-12 in), and the remainder gravel (2 to 4 in).
Velocities (range):	Surface: 2 - 10+ ft/s. Near bottom: 5 - 10+ ft/s.
Dates surveyed:	6, 12, and 18 Nov 1986.
No. transect lines:	7 (150-ft intervals).
Spawning:	66 redds on peak survey day (12 Nov), 98 total redds counted, maximum redd depth was 10 ft.
Dimensions of spawning area:	Approx. 900 X 500 ft (450,000 ft^2 or 10 acres) to 10 ft deep.

Locke Island Site--RM 374.2

Miles below Priest Rapids Dam: 22.8.

Dimensions:	2,100 ft long X about 1,500 ft wide (3,150,000 ft^2 or 72 acres).
Maximum depth:	24 ft, based on vegetation line of 379 ft el.
River bottom materials:	Western 2/3 of this site had gradual slope to deepest channel and was covered with one large portion of gravel (2-4 in). Eastern 1/3 was covered with very large boulders and unsuitable for spawning.
Velocities (range):	Surface: 2.0 - 5.7 ft/s. Near bottom: 5.6 - 9.0 ft/s.
Dates surveyed:	15, 23, 28 Oct and 4, 13 Nov 1986
No. transect lines:	14 (150-ft intervals).
Spawning:	Only 5 redds (to a depth of 15 ft) were observed in this area despite its apparent suitability for spawning.
Remarks:	Abandoned survey of this site on 13 Nov.

Upper Locke Island Site--RM 375.5

Miles below Priest Rapids Dam:	21.5.
Dimensions:	900 ft long x 1,200 ft wide at the upstream end, narrowing to about 800 ft at the downstream end (approx. 945,000 ft^2 or 22 acres).
Maximum depth:	25 ft, based on vegetation line of 375 ft el.
River bottom materials:	Southern 1/3 was composed of rubble (4-8 in). Central majority of site was covered with rock (8-12 in). Northwest corner was sand. A narrow band of very large boulders were settled along an overhanging underwater ledge and the main channel ran through this narrow band.
Velocities (range):	Surface: 3.0 - 10+ ft/s. Near bottom: 3.8 - 10+ ft/s.
Dates surveyed:	7, 13, and 19 Nov 1986
No. transect lines:	14 (50-ft intervals)
Spawning:	180 redds on peak survey day (19 Nov), 267 total redds counted.
Dimensions of spawning area:	Approx. 700 X 450 ft (315,000 ft^2 or 7 acres) to 25 ft deep (80% 5-15 ft, remainder 15-25 ft).

Coyote Rapids Site--RM 381.8

Miles below Priest Rapids Dam: 15.2.

Dimensions:	2,100 ft long X about 1,200 ft wide (2,520,000 ft^2 or 58 acres).
Maximum depth:	40 ft, based on vegetation line of 387 ft el.
River bottom materials:	Southern half was suitable rock (8-12 in) and rubble (4-8 in) for fall chinook salmon, but the velocity was very low. Northern half was covered mostly with boulders (12 in and up) and high velocities.
Velocities (range):	Surface: 2 - 8.6 ft/s Near bottom: 3.5 - 5.3 ft/s
Dates surveyed:	17, 26, and 29 Oct and 11 Nov 1986
No. transect lines:	14 (150-ft intervals).
Spawning:	None observed.
Remarks:	Abandoned survey of this site 11 Nov.

Midway Site--RM 391.8

Miles below Priest Rapids Dam:	5.2.
Dimensions:	1,950 ft long X about 1,200 ft wide (2,145,000 ft^2 or 49 acres).
Maximum depth:	30 ft, based on vegetation line of 400 ft el.
River bottom materials:	Primarily rubble (4-8 in) with large areas of rock (8-12 in) near each shoreline. A strip of gravel (2-4 in) about 200 ft wide was just north of and parallel to the river's centerline. However, the concentrated spawning was observed in a large area of rubble almost centered in the site. It was about 700 ft wide at the upstream end tapering to about 150 ft wide at the downstream end.
Velocities (range):	Surface: 2.8 - 7.7 ft/s. Near bottom: 2.5 - 5.2 ft/s.
Dates surveyed:	21 and 30 Oct and 10, 17, and 20 Nov 1986
No. transect lines:	14 (150-ft intervals).
Spawning:	182 redds on peak survey day (17 Nov), 384 total redds counted.
Dimensions of spawning area:	Approx. 1,950 ft X 250 ft (487,500 ft^2 or 11 acres), about 23% of the study area with redds to 30 ft deep (virtually all 20-25 ft).
Remarks:	Divers estimated more live fish observed on 17 Nov at this site than on all other survey days at other sites.

Vernita Bar Site--RM 392.8

Miles below Priest Rapids Dam: 4.2.

Dimensions:	1,950 ft long X about 600 ft wide (1,170,000 ft^2 or 27 acres).
Maximum depth:	23 ft, based on vegetation line of about 400 ft el.
River bottom materials:	Primarily all rubble (4-8 in) and occasional scattered large boulders, with the exception of a large section of rock (8-12 in) in the northern portion of the site. Virtually all spawning was found in rubble substrate.
Velocities (range):	Surface: 2.4 - 10+ ft/s. Near bottom: 2.0 - 10+ ft/s.
Dates surveyed:	8, 16, and 21 Nov 1986
No. transect lines:	14 (150-ft intervals).
Spawning:	140 redds on peak day (16 Nov), 163 total redds counted.
Dimensions of spawning area:	Approx. 150 X 1,950 ft (292,500 ft^2 or 7 acres) to 23 ft deep; 70% 10-15 ft deep.

Vernita Site--RM 394.0

Miles below Priest Rapids Dam:	3.0
Dimensions:	2,100 ft long X 1,500 ft wide (3,1500,00 ft^2 or 72 acres).
Maximum depth:	39 ft, based on vegetation line of 407 ft el.
River bottom materials:	Predominantly rubble (4-8 in) and rock (8-12 in) with some boulders (12 in or greater) on the south shoreline and large patches of gravel (2-4 in) randomly scattered throughout.
Velocities (range):	Surface: 2.6 - 5.7 ft/s - sled under tow. Near bottom: 1.8 - 5.9 ft/s - sled under tow.
Dates surveyed:	20 Oct and 3, 9, and 14 Nov 1986
No. transect lines:	14 (150-ft intervals).
Spawning:	88 redds on peak survey day (9 Nov), 217 total redds counted.
Dimensions of spawning area:	Approx. 200 ft X 2,000 ft (400,000 ft^2 or 9 acres) to 22 ft. deep. Virtually all were 10-15 ft deep.
Remarks:	On 9 November, special current-velocity readings were taken with the boat stationary, the sled on bottom (10-12 ft deep), and the discharge from Priest Rapids Dam was at 64 Kft^3/s.

Location within survey site	Location within water column	Velocity (ft/s)
North of redds	Surface	2.4
	Near bottom	1.4
In redds	Surface	2.1
	Near bottom	2.1
South of redds	Surface	2.5
	Near bottom	2.4