

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof. Reference herein to any social initiative (including but not limited to Diversity, Equity, and Inclusion (DEI); Community Benefits Plans (CBP); Justice 40; etc.) is made by the Author independent of any current requirement by the United States Government and does not constitute or imply endorsement, recommendation, or support by the United States Government or any agency thereof.

Hanford Reach Fall Chinook Salmon Redd Monitoring Report for Calendar Year 2021



Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract 89303320DEM000031



P.O. Box 943
Richland, Washington 99352

This page intentionally left blank.

Hanford Reach Fall Chinook Salmon Redd Monitoring Report for Calendar Year 2021

J. J. Nugent, HMIS

Hanford Mission Integration Solutions
Richland, WA

Date Published
March 2023

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management



**P.O. Box 943
Richland, Washington 99352**



Release Approval

Date

TRADEMARK DISCLAIMER

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

This report has been reproduced from the best available copy.

Printed in the United States of America
Cover Photo: Chinook redds as seen from an aerial survey.

CONTENTS

1.0	INTRODUCTION.....	1
2.0	METHODS	2
3.0	RESULTS.....	6
4.0	DISCUSSION	7
5.0	REFERENCES.....	9

FIGURES

1.	Aerial Survey Areas for Fall Chinook Salmon Redds Used Historically and in Calendar Year 2021	4
2.	Fall Chinook Salmon Survey Sub-Areas Adjacent to Groundwater Contamination Plumes.....	5
3.	Visual Hanford Reach Fall Chinook Salmon Redd Counts 1948 to 2021	8
4.	Gauge Height Changes at USGS 12472800 Columbia River Below Priest Rapids Dam During the Fall Chinook Salmon Spawning Period in Calendar Year 2021	9

TABLES

1.	Summary of Fall Chinook Salmon Visual Aerial Redd Counts for Calendar Year 2021 Aerial Surveys in the Hanford Reach, Columbia River.....	6
2.	Summary of Fall Chinook Salmon Visual Aerial Redd Counts for the Calendar Year 2021 Aerial Surveys by Operational Area Subsections	7

1.0 INTRODUCTION

The U.S. Department of Energy, Richland Operations Office (DOE-RL), conducts ecological monitoring on the Hanford Site to collect and track data needed to ensure compliance with an array of environmental laws, regulations, and policies governing DOE-RL activities. Ecological monitoring data provide baseline information about the plants, animals, and habitats under DOE-RL stewardship at the Hanford Site required for decision making under the *National Environmental Policy Act* (NEPA) and *Comprehensive Environmental Response, Compensation, and Liability Act*. DOE/EIS-0222, *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement*, (CLUP) evaluates the potential environmental impacts associated with implementing a comprehensive land-use plan for the Hanford Site for at least the next 50 years, and ensures that DOE-RL, its contractors, and other entities conduct activities on the Hanford Site in compliance with NEPA.

The vision for the DOE-RL-managed portion of the Hanford Site focuses on the cleanup of nuclear facilities and waste sites, the protection of groundwater and the Columbia River, and the restoration of the Hanford Site lands for access and use (DOE/RL-2009-10). DOE-RL is working closely with partners, such as the U.S. Fish and Wildlife Service and National Park Service, to enable use of the Hanford Site land consistent with the CLUP. As the Hanford Site moves toward accomplishing this vision, monitoring the ecological resources present to determine whether there is a need for conservation and/or protection of any resources will be critical for making informed decisions for responsible site stewardship.

DOE-RL places priority on monitoring plant and animal species or habitats that fit into one or more of the categories below:

- Regulatory protections or requirements
- Rare and/or declining species (i.e., federally or state listed endangered, threatened, or sensitive)
- Significant interest to federal, state, or Tribal governments or the public.

DOE/RL-96-32, *Hanford Site Biological Resources Management Plan*, (BRMP) ranks wildlife species and habitats (Levels 0–5) based on the level of concern for each resource. Fall Chinook salmon (*Oncorhynchus tshawytscha*) spawning areas are ranked as Level 5 resources, the highest-ranking level in BRMP. According to the BRMP, “resources classified as Level 5 are the rarest and most sensitive habitats and species and are considered irreplaceable or at risk of extirpation or extinction.” The management goal of Level 5 resources is preservation and requires a high level of status monitoring.

Commonly referred to as king salmon, Chinook are the largest of the Pacific salmon (Myers et al. 1998, Netboy 1958). The Columbia River supports three major runs (spring, summer, and fall) of Chinook salmon. Each run is generally based on the season during which the adults re-enter the estuary to begin their upstream migration to spawn. Chinook salmon that spawn in the Hanford Reach of the Columbia River are fall-run fish. Fall Chinook salmon enter freshwater at an advanced stage of maturity, move rapidly to their spawning areas on the mainstem or lower tributaries of the rivers, and spawn within a few days or weeks of freshwater entry (Myers et al. 1998, Fulton 1968, Healey 1991). Adult fall Chinook salmon destined for the Hanford Reach are upriver brights (fish retain their silver color during upstream migration) that enter the Columbia River in late summer and spawn in the fall. Spawning in the Hanford Reach typically begins in mid-October and lasts through November. The population of fall Chinook salmon that spawns in the Hanford Reach of the Columbia River is the largest run remaining in the Pacific Northwest and has regional, ecological, cultural, and economic importance that reaches areas downstream on the Columbia River and along the Pacific Ocean coast as far as southeast Alaska (Dauble and Watson 1997). These fall Chinook

salmon have been vital in efforts to preserve and restore other depleted Chinook salmon stocks in the Columbia Basin (Anglin et al. 2006).

Dauble and Watson (1997) found the initiation of spawning ranged from September 28 to October 26 with a median date of October 16. Females fan out nests or “redds” in suitable gravel substrate and deposit eggs in a pocket while males simultaneously extrude milt to fertilize the eggs. Redds are readily identifiable at this time and appear as clean swept gravel patches amidst darker undisturbed substrate covered by algae (periphyton). “Redd life” is a term describing the period during which periphyton growth has not rendered the redd substrate indiscernible from the surroundings. Redd life is typically about 6 weeks on the Hanford Reach (PNL-7289). Redds, however, have been recorded to remain visible for over 16 weeks (HNF-53665, HNF-56705).

Fall Chinook salmon redds have been monitored at the Hanford Site annually since 1948, including aerial counts, to provide an index of relative abundance among spawning areas and years (HNF-52190, HNF-54808, HNF-56707, HNF-58823, HNF-59813, HNF-63012, HNF-64540, HNF-64542, HNF-65646, HNF-66775). The counts are used to document the onset of spawning, locate spawning areas, and determine intervals of peak spawning activity. These data also allow for planning to avoid impacts such as disturbance or siltation to redds from Hanford Site activities. Understanding the location and abundance of spawning is a critical part of the management of this important population and facilitates protection of essential fish habitats safeguarded under the *Magnuson-Stevens Fishery Conservation and Management Act*.

The information collected during the aerial surveys is vitally important to the implementation of the Hanford Reach Fall Chinook Protection Program (HRFCPP; USACE 2006). The HRFCPP is an agreement among Public Utility District No. 2 of Grant County, Washington (Grant); Public Utility District No. 1 of Chelan County, Washington (Chelan); Public Utility District No. 1 of Douglas County, Washington (Douglas); Department of Energy acting by and through the Bonneville Power Administration (BPA); National Oceanic and Atmospheric Administration Fisheries (NOAAF); Washington Department of Fish and Wildlife (WDFW); and the Confederated Tribes of the Colville Indian Reservation (CCT). The goal of this program is to protect Hanford Reach fall Chinook salmon during critical periods of their life cycle through operational constraints imposed on the Priest Rapids Hydroelectric Project.

2.0 METHODS

Aerial surveys of fall Chinook salmon redds were conducted in areas of the Hanford Reach consistent with past survey efforts and the historical data set (Figure 1). Eight additional subsections (100-B/C, 100-K, 100-N, 100-D, 100-H, 100-F, Dunes, and 300 Area) were added beginning in 2011 to monitor the abundance and distribution of fall Chinook salmon redds in areas of the Columbia River adjacent to contaminated groundwater plumes of the Hanford Site (Figure 2; DOE/RL-2018-32). These eight new subsections were divided so that redd counts and direct comparisons to historical records can still be made in the original areas.

The primary physical factors influencing the accuracy of aerial counts include depth of water over redds and water clarity. Wind action, available light, orientation of the river, and direction of the current can also affect redd counts. The accuracy of aerial counts also decreases with increasing numbers and density of redds within a large aggregate of redds (Visser et al. 2002). Flights are cancelled if weather conditions are not favorable (i.e., wind, fog, or low clouds). Field measurements suggest that the upper depth limit

for detecting redds during aerial surveys conducted on the Hanford Reach was 3 to 4 m (10 to 13 ft) (PNL-7289), while other studies indicate that fall Chinook salmon spawn in water up to 9 m (30 ft) deep (Swan 1989); therefore, a proportion of redds located in deeper water may not be detected during aerial surveys (PNL-7289). As it is seldom possible to view all redds from the air, these counts provide only an annual index of relative abundance and distribution of fall Chinook salmon spawning in the Hanford Reach of the Columbia River.

Beginning in mid-October, under the terms of the HRFCPP, river flows are reduced in the morning every Sunday (the day of the week with the lowest power demand) to the Priest Rapids Dam minimum operating discharge of 1,000 m³/sec (36,000 ft³/sec). This allows the Agency (NOAAF, WDFW, and CCT) and Utility (Grant, Chelan, Douglas, and BPA) Party Monitoring Team to perform a ground survey of redd distribution at Vernita Bar just downstream of Priest Rapids Dam. These drawdowns occur every Sunday morning until the initiation of fall Chinook salmon spawning has been set both above and below the 1,416 m³/sec (50,000 ft³/sec) flow elevations. A final drawdown is conducted on the Sunday prior to Thanksgiving to establish the minimum critical flow needed to protect pre-emergent fall Chinook salmon. This weekly reduction in river flow can afford excellent viewing conditions and, when possible, flights are scheduled concurrent with the Sunday morning drawdowns.

Flights are scheduled to encompass the entire fall Chinook salmon spawning period, usually mid-October (initiation of spawning) through the end of November (end of spawning). Three to four flights are typically conducted during this period. Early flights (October) are conducted to establish the initiation of spawning; later flights (November) occur during and just after the peak spawning period to establish the maximum redd count for the season by area and for the entire Hanford Reach. Multiple flights are necessary to minimize the effects of poor visibility or other sources of count variability that may occur during a single flight. Multiple flights also ensure comparability within the long-term database through consistency with past efforts. As a courtesy and consistent with past practices, aerial redd count information is shared with the HRFCPP parties to assist in the implementation of protective measures.

Survey flight altitudes range from 244 to 366 m (800 to 1,200 ft) with air speeds of 120 to 161 km/hr (75 to 100 mi/hr). Widely spaced fall Chinook salmon redds are individually counted, while tightly grouped clusters of redds are estimated in groups of 10 or 50. Heavy spawning areas require multiple aerial passes to collect complete counts. Observations begin in Richland at the Interstate 182 bridge and end at Priest Rapids Dam. Flights are conducted near noon to bracket the highest angle of the sun for optimum viewing conditions. Observers wear polarized glasses, as necessary, to reduce glare. All redds observed are documented by survey area on large format printed maps.

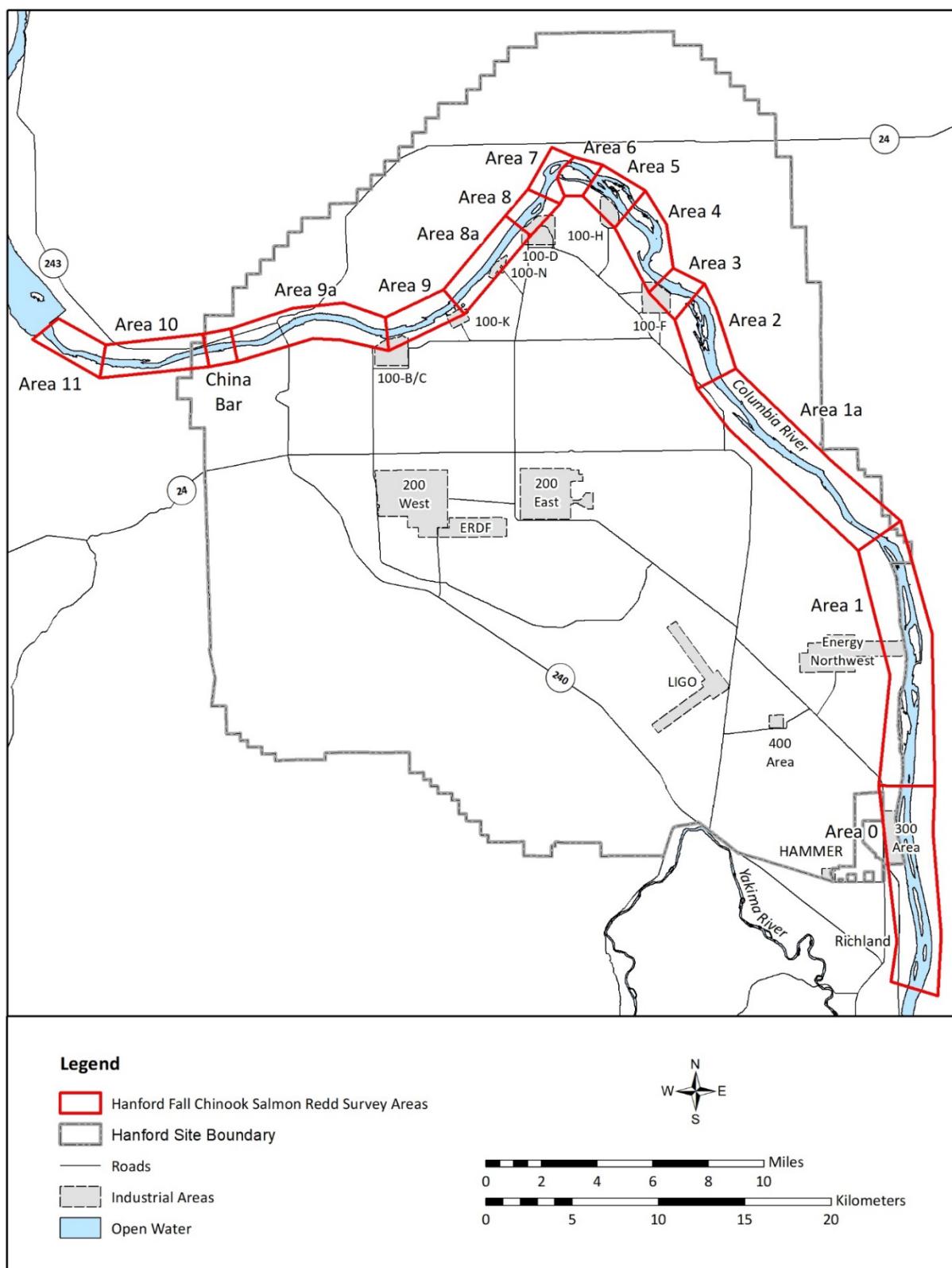


Figure 1. Aerial Survey Areas for Fall Chinook Salmon Redds Used Historically and in Calendar Year 2021

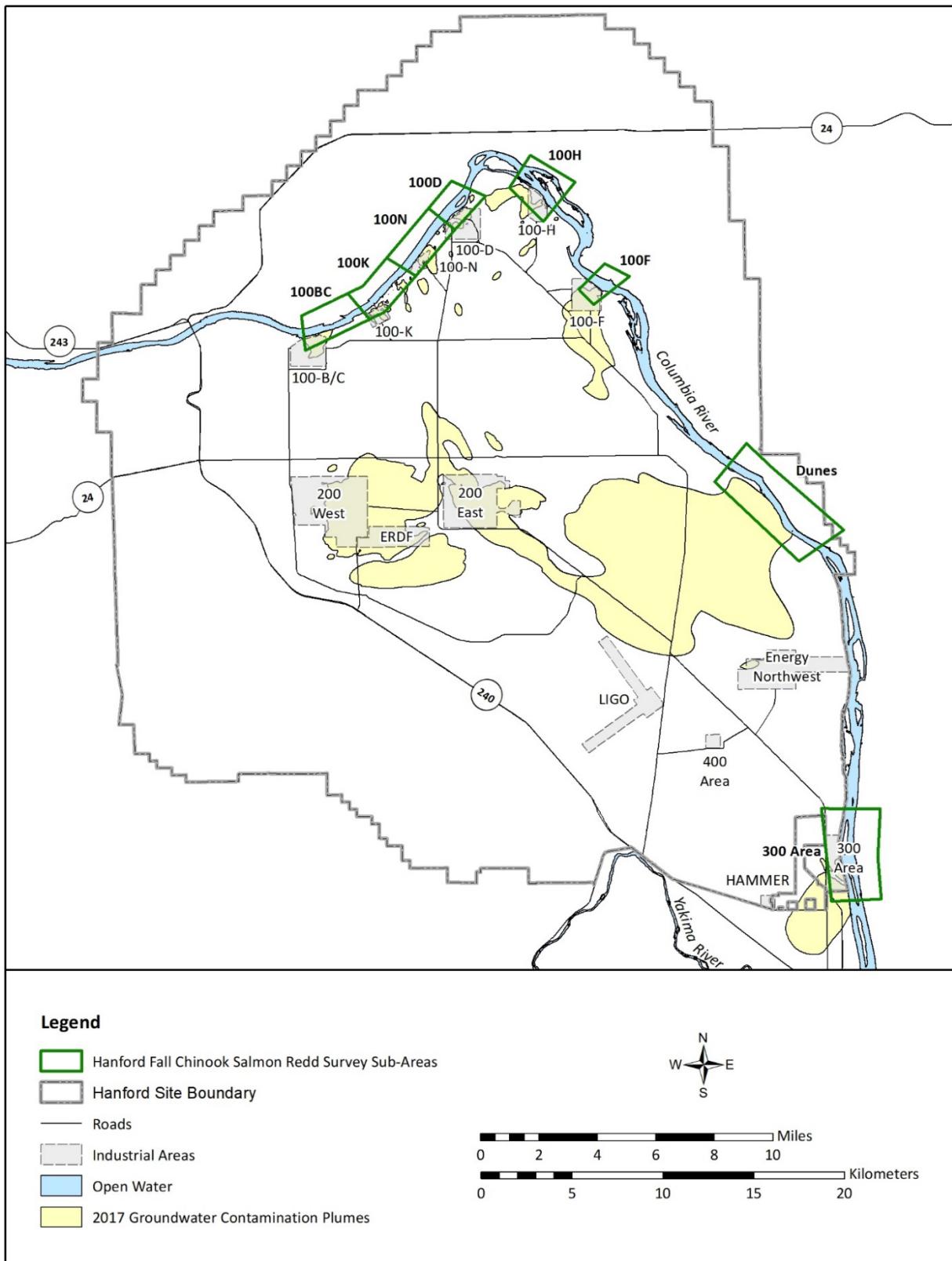


Figure 2. Fall Chinook Salmon Survey Sub-Areas Adjacent to Groundwater Contamination Plumes

As long-term trends in both redd abundance and distribution are important monitoring components, Hanford Mission Integration Solutions has taken the following steps to ensure compatibility and consistency with past efforts:

- Thoroughly reviewing and adopting past monitoring protocols
- Coordinating/training with former redd count personnel
- Coordinating and exchanging information with the WDFW and with the Grant County Public Utility District to support the ongoing HRFCPP
- Using maps detailing the entire survey reach as well as all historical sub-areas and spawning sites both as in-flight guidance documents and as field data recording forms
- Using the same air service, airplane, and pilots in 2021 that were used in previous years.

3.0 RESULTS

Three fall Chinook salmon visual aerial redd count surveys were completed along the length of the Hanford Reach during 2021. The first visual aerial redd count survey was performed on October 21, the second on November 3, and the third on November 17. The counts performed during each flight are shown by survey area in Table 1. The maximum count describes the highest number of redds documented in a survey area within any single flight. The visual redd count total is calculated by summing the maximum redd count from each survey area, which equaled 9,639 in 2021. The number of redds counted within the newer defined sub-areas coinciding with Hanford Site operational areas is shown in Table 2. Viewing conditions were excellent on the first flight (October 21). Viewing conditions on the second flight (November 3) and third flight (November 17) were good, although silt plumes were observed along sections of the eastern shoreline of the river from Locke Island to below Wooded Island, obscuring some redds from view on the third flight.

Table 1. Summary of Fall Chinook Salmon Visual Aerial Redd Counts for Calendar Year 2021 Aerial Surveys in the Hanford Reach, Columbia River (2 Pages)

Area	Description	10/21/2021	11/03/2021	11/17/2021	Maximum Count
0	Islands 17–21 (Richland)	0	0	0	0
1	Islands 11–16	43	194	507	507
1a	Savage Island/Hanford Slough	0	0	0	0
2	Islands 8–10	29	407	432	432
3	Near Island 7	10	506	612	612
4	Island 6 (lower half)	24	1,082	1,102	1,102
5	Island 4, 5, and upper 6	21	822	1,580	1,580
6	Near Island 3	0	280	350	350
7	Near Island 2	23	750	1,050	1,050
8	Near Island 1	0	70	70	70
8a	Upstream of Island 1 to Coyote Rapids	0	0	0	0

**Table 1. Summary of Fall Chinook Salmon Visual Aerial Redd Counts for Calendar Year 2021
Aerial Surveys in the Hanford Reach, Columbia River (2 Pages)**

Area	Description	10/21/2021	11/03/2021	11/17/2021	Maximum Count
9	Near Coyote Rapids	2	109	109	109
9a	Upstream of Coyote Rapids to China Bar	0	0	0	0
China Bar	China Bar/Midway	0	15	20	20
10	Near Vernita Bar	280	3,800	3,800	3,800
11	Upstream of Vernita Bar to Priest Rapids Dam	0	7	7	7
Total		432	8,042	9,639	9,639

Table 2. Summary of Fall Chinook Salmon Visual Aerial Redd Counts for the Calendar Year 2021 Aerial Surveys by Operational Area Sub-Sections

Sub-Area	10/21/2021	11/03/2021	11/17/2021	Maximum Count
300 Area	0	0	0	0
Dunes	0	0	0	0
100-F	10	506	612	612
100-H	21	822	1,580	1,580
100-D	0	70	70	70
100-N	0	0	0	0
100-K	0	0	0	0
100-BC	2	109	109	109
Total	33	1,507	2,371	2,371

4.0 DISCUSSION

The peak annual visual redd count for 2021 (9,639) was the sixth highest count (range: 4,018 – 20,678) in the past 20 years (2002 – 2021) and was well below the previous 10-year average (11,670). Fall Chinook salmon redd counts on the Hanford Reach in 2021 decreased by 5.0% from the 2020 redd count (10,150). The historical trend in redd counts since 1948 is shown in Figure 3.

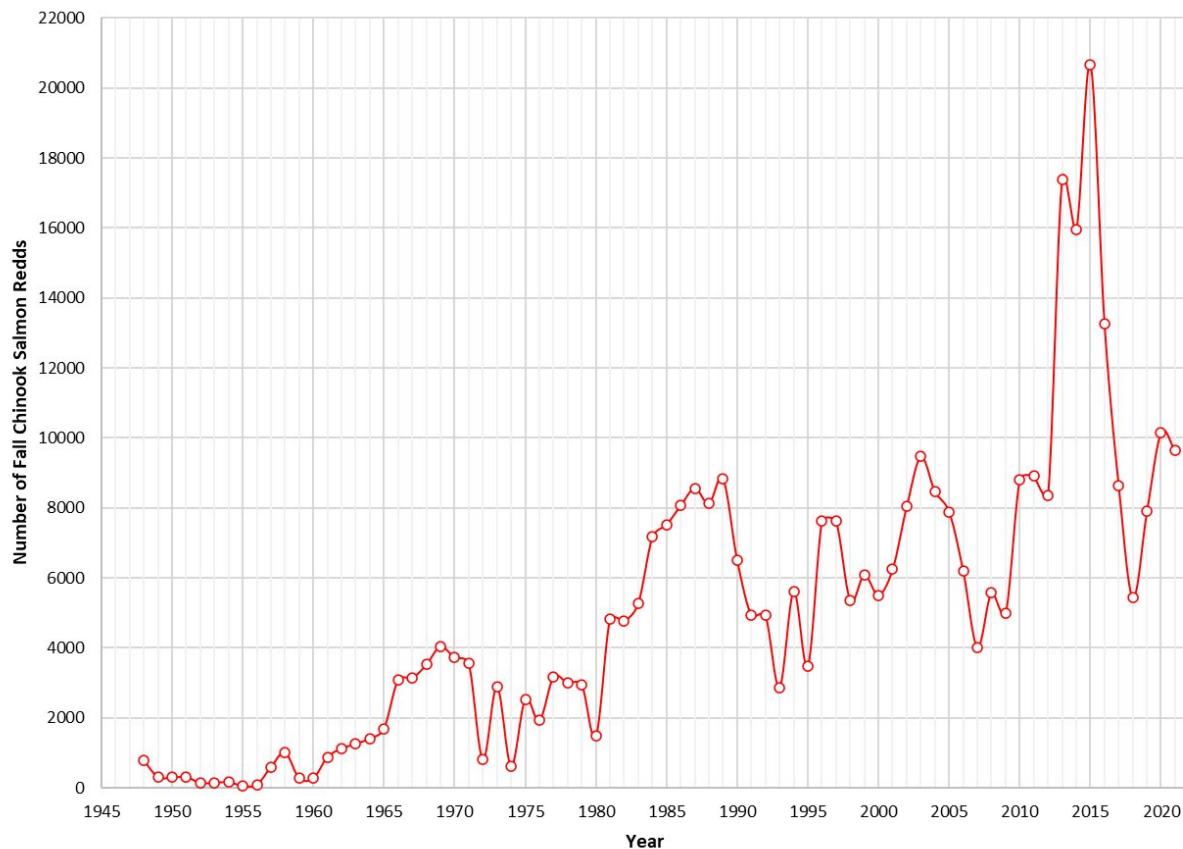


Figure 3. Visual Hanford Reach Fall Chinook Salmon Redd Counts 1948 to 2021

Silt plumes were again observed in the Hanford Reach during the fall Chinook salmon spawning period in 2021. These now annual occurrences are likely the result of large rapid fluctuations in river flows that cause instability and slumping of sediments at the toes of the landslides along the White Bluffs; they are assumably impacting redds and degrading spawning habitat in the middle and lower sections of the Hanford Reach (HNF-65646). Mean daily flow fluctuations were 2.1 m (6.7 ft) (range: 0.6 – 3.9 m [2.1 - 12.8 ft]) on the Hanford Reach during the fall Chinook salmon spawning period in 2021 (October 15 to November 21). Figure 4 shows river gauge height changes at the United States Geological Survey (USGS) 12472800 station on the Columbia River below Priest Rapids Dam during the fall Chinook salmon spawning period (USGS 2023).

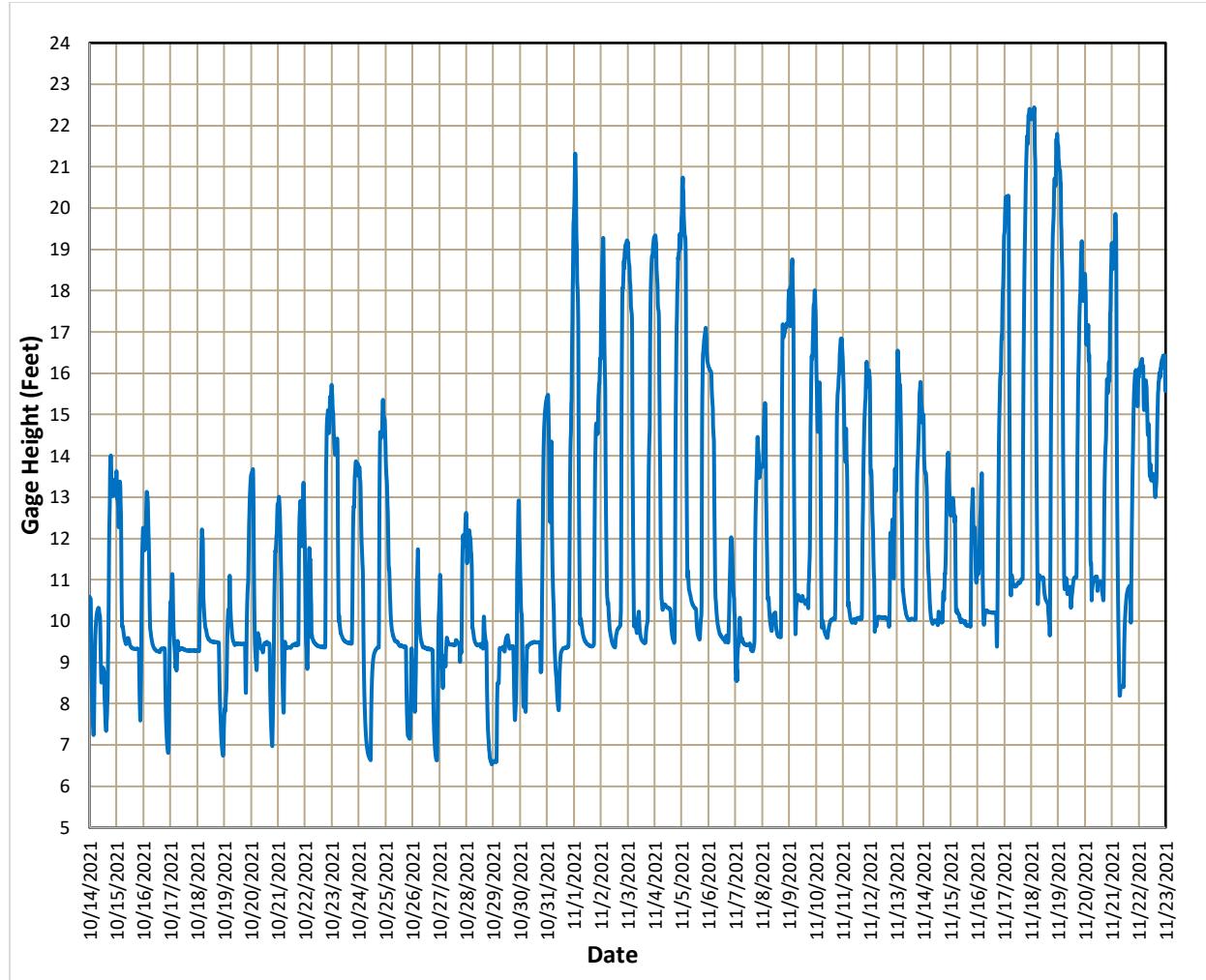


Figure 4. Gauge Height Changes at USGS 12472800 Columbia River Below Priest Rapids Dam During the Fall Chinook Salmon Spawning Period in Calendar Year 2021 (USGS 2023)

5.0 REFERENCES

Anglin, D. R., S. L. Haeseker, J. J. Skalicky, H. Schaller, K. F. Tiffan, J. R. Hatten, P. Hoffarth, J. Nugent, D. Benner, and M. Yoshinaka. 2006. *Effects of Hydropower Operations on Spawning Habitat, Rearing Habitat, and Stranding/Entrapment Mortality of Fall Chinook Salmon in the Hanford Reach of the Columbia River*. U.S. Fish and Wildlife Service, Technical Report Vancouver, Washington.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980, 42 U.S.C. 9601-9675. (P.L. 96-510). Online at: <https://www.govinfo.gov/content/pkg/USCODE-2011-title42/html/USCODE-2011-title42-chap103.htm>.

Dauble, D. D. and D. G. Watson. 1997. "Status of Fall Chinook Salmon Populations in the Mid-Columbia River, 1948–1992." *North American Journal of Fisheries Management* 17 (2): 283–300. Online at: [http://dx.doi.org/10.1577/1548-8675\(1997\)017<0283:sofcsp>2.3.co;2](http://dx.doi.org/10.1577/1548-8675(1997)017<0283:sofcsp>2.3.co;2).

DOE/EIS-0222. 1999. *Final Hanford Comprehensive Land-Use Plan Environmental Impact Statement*. U.S. Department of Energy, Washington, D. C. Online at: <http://energy.gov/nepa/downloads/eis-0222-final-environmental-impact-statement-0>.

DOE/RL-2009-10. 2013. *Hanford Site Cleanup Completion Framework*. Rev. 1. U.S. Department of Energy, Richland Operations Office, Richland, Washington. Online at: https://www.hanford.gov/files.cfm/Comp_Framework_Jan %201-23-13-lfm.pdf.

DOE/RL-96-32. 2017. *Hanford Site Biological Resources Management Plan*. Rev. 2. U.S. Department of Energy, Richland Operations Office, Richland, Washington. Online at: <http://www.hanford.gov/files.cfm/DOE-RL-96-32-01.pdf>.

DOE-RL-2018-32. 2018. *Hanford Annual Site Environmental Report for Calendar Year 2017*. Rev. 0. U.S. Department of Energy, Richland Operations Office, Richland, Washington. Online at: <https://pdw.hanford.gov/document/AR-19751>.

Fulton, L. A. 1968. *Spawning Areas and Abundance of Chinook Salmon (Oncorhynchus tshawytscha) in the Columbia River Basin--Past and Present*. U.S. Fish and Wildlife Service Special Scientific Report--Fisheries No. 571. U.S. Fish and Wildlife Services, Bureau of commercial Fisheries, Washington, D.C. Online at: http://www.nwfsc.noaa.gov/assets/26/6638_08042010_145107_Fulton.1968-rev.pdf.

Healey, M. C. 1991. *The Life History of Chinook Salmon (Oncorhynchus tshawytscha)*. University of British Columbia Press, Vancouver, British Columbia, Canada.

HNF-52190. 2012. *Fall Chinook Redd Monitoring Report Calendar Year 2011*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/hnf-52190 - rev_0%20public%20releseed.pdf.

HNF-53665. 2012. *Steelhead Redd Monitoring Report for Calendar Year 2012*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/hnf-53665 - rev_00.pdf.

HNF-54808. 2013. *Hanford Reach Fall Chinook Redd Monitoring Report for Calendar Year 2012*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/hnf-54808 - rev_00_nc.pdf.

HNF-56705. 2014. *Hanford Site Steelhead Redd Monitoring Report for Calendar Year 2013*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/HNF-56705 - Rev_00.pdf.

HNF-56707. 2014. *Hanford Reach Fall Chinook Redd Monitoring Report for Calendar Year 2013*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/HNF-56707 - Rev_00.pdf.

HNF-58823. 2015. *Hanford Reach Fall Chinook Redd Monitoring Report for Calendar Year 2014*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: http://www.hanford.gov/files.cfm/HNF-58823 - Rev_00.pdf.

HNF-59813. 2016. *Hanford Reach Fall Chinook Redd Monitoring Report for Calendar Year 2015*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: https://www.hanford.gov/files.cfm/HNF-59813 - Rev_00.pdf.

HNF-63012. 2018. *Hanford Site Ecological Monitoring Report for Calendar Year 2017*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: https://www.hanford.gov/files.cfm/HNF-63012 - Rev_00_cleared.pdf.

HNF-64540. 2020. *Hanford Reach Fall Chinook Salmon Redd Monitoring Report for Calendar Year 2017*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: <https://www.hanford.gov/page.cfm/EcologicalMonitoring>.

HNF-64542. 2020. *Hanford Reach Fall Chinook Salmon Redd Monitoring Report for Calendar Year 2018*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: https://www.hanford.gov/files.cfm/HNF-64542 - Rev_00.pdf.

HNF-65646. 2020. *Hanford Reach Fall Chinook Salmon Redd Monitoring Report for Calendar Year 2019*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: https://www.hanford.gov/files.cfm/HNF_65646_Rev01.pdf.

HNF-66775. 2021. *Hanford Reach Fall Chinook Salmon Redd Monitoring Report for Calendar Year 2020*. Rev. 0. Mission Support Alliance, Richland, Washington. Online at: https://www.hanford.gov/files.cfm/HNF-66775 - Rev_00.pdf.

Magnuson-Stevens Fisheries Conservation and Management Act, 16 U.S.C. 1801-1884. Online at: <https://www.govinfo.gov/content/pkg/USCODE-2017-title16/html/USCODE-2017-title16-chap38.htm>.

Myers, J. M., R. G. Kope, G. J. Bryant, D. Teel, L. J. Lierheimer, T. C. Wainwright, W. S. Grant, F.W. Waknitz, K. Neely, S. T. Lindley, and R. S. Waples. 1998. *Status Review of Chinook Salmon from Washington, Idaho, Oregon, and California*. U.S. Department of Commerce: NOAA Technical Memorandum NMFS-NWFSC-35. 443 pp. Online at: http://www.westcoast.fisheries.noaa.gov/publications/status_reviews/salmon_steelhead/chinook/sr1998-chinook1.pdf.

National Environmental Policy Act of 1969, 42 U.S.C. 4321, et seq. Online at: http://energy.gov/sites/prod/files/nepapub/nepa_documents/RedDont/Req-NEPA.pdf.

Netboy, A. 1958. *Salmon of the Pacific Northwest: Fish vs. Dams*. Binfords & Mort, Portland, Oregon.

PNL-7289. 1990. *Spawning and Abundance of Fall Chinook Salmon (*Oncorhynchus Tshawytscha*) in the Hanford Reach of the Columbia River, 1948 – 1988*. Rev. 0. Pacific Northwest Laboratory, Richland, Washington. Online at: <https://www.osti.gov/servlets/purl/7051730-JJuOej/>.

Swan, G. A. 1989. “Chinook Salmon Spawning Surveys in Deep Waters of a Large, Regulated River.” *Regulated Rivers: Research & Management* 4 (4): 355–370. Online at: http://www.nwfsc.noaa.gov/assets/2/7293_07122012_094837_Swan.1989.pdf.

USACE. 2006. Hanford Reach Fall Chinook Protection Program, Hanford Reach Fall Chinook Protection Program Executed Agreement. U.S. Army Corps of Engineers. Online at: <http://pweb.crohms.org/tmt/documents/wmp/2006/draft/app7.pdf>.

USGS. 2023. United States Geological Survey Gauging Station # 12472800 Columbia River Below Priest Rapids Dam, Washington. Accessed January 2023. Online at: https://waterdata.usgs.gov/usa/nwis/uv?site_no=12472800.

Visser, R., D. D. Dauble, and D. R. Geist. 2002. "Use of Aerial Photography to Monitor Fall Chinook Salmon Spawning in the Columbia River." *Transactions of the American Fisheries Society* 131 (6): 1173–1179. Online at: [http://dx.doi.org/10.1577/1548-8659\(2002\)131<1173:uoaptm>2.0.co;2](http://dx.doi.org/10.1577/1548-8659(2002)131<1173:uoaptm>2.0.co;2).