White Bluffs Landslides

Assessment Report

Prepared under Contract to
The US Institute for Environmental Conflict Resolution and
The US Fish and Wildlife Service
for the
Hanford Reach National Monument

Prepared by
Triangle Associates, Inc.
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  Dan Hubbs, US Bureau of Reclamation
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  Mark Nielson, Franklin Conservation District
  Robert L. Schuster, US Geological Survey Scientist Emeritus
  Paul Stoker, Columbia Basin Groundwater Management Area
  Ken Tiffan, US Geological Survey

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Executive Summary

Background

Majestic White Bluffs line the eastern shores of the Hanford Reach of the Columbia River, opposite the Hanford site. These White Bluffs vary in height from 150 to 500 feet above the river and extend approximately 30 miles north of the Tri-Cities in south-central Washington.

Over the last 30 years, landslides (also commonly referred to as slumping or sloughing) have occurred at a number of places along the White Bluffs. This assessment of the White Bluffs Landslides was undertaken because of concerns about impacts of the landslides on the Hanford Reach National Monument. Its purpose was to identify what is causing the landslides, what their impacts are, and to identify what, if anything, can be done to reduce the rate of the landslides and to minimize their impacts on public and private lands.

Assessment Process

Interviews

In April 2003, with support provided by the US Institute of Environmental Conflict Resolution, Triangle Associates initiated the assessment process. The Ad Hoc Conflict Resolution Subcommittee of the Hanford Reach National Monument Federal Planning Advisory Committee guided the assessment. The process began with interviews with a wide range of parties to identify issues and concerns related to the landslides (causes and impacts) and to invite process suggestions on how to make progress in addressing the landslides. (*Appendix D identifies those who participated in the interviews*.) Many of those interviewed identified questions related to the landslides and spoke of the need for up-to-date, reliable information about the causes of the landslides and their impact, in particular, on fish and fish habitat.

Literature review

The assessment process also included a review of published information about the landslides – studies, reports, and newspaper articles. The published information is summarized in the first chapter of this report. With the exception of three studies that were conducted at Locke Island in the late 1990s, most of these studies were published before 1990. No other landslide areas in the White Bluffs have been systematically studied since 1989.

Technical Workshops

The questions identified through the interview process became the focus of three technical workshops that were held in January 2003. The purpose of the technical workshops was to explore information concerning the landslides as they relate to three issues:

- Geology/Landslides
- Water/Groundwater/Irrigated Agriculture
- Impacts to Fish and Habitat

Workshop participants were selected based on their expertise, relevant knowledge and the range of perspectives they represented.

At the conclusion of the workshops, participants were in agreement that information about the causes and impacts of the White Bluffs landslides is inadequate and that further studies must be conducted in a systematic and coordinated manner before remedial actions are undertaken.

Major Conclusions

Workshop participants were in agreement on the following conclusions related to the White Bluffs landslides.

Workshops on Geology/Landslides and on Water/Groundwater/Irrigated Agriculture

- The similarities in the causes of landslides at different locations are that water is being added to the system and, in every case, water is a major contributing factor to slope instability.
- There is not adequate information about the underlying geology of the White Bluffs to characterize landslide hazards. If sufficient water is added to the fine-grained sediments of the Ringold Formation at the steep face of the White Bluffs, slope failure occurs in the form of landslides. However, the specific mechanisms and processes that form landslides along the bluffs are not known. There are not enough data to explain these results or to predict future landslide activity.
- No one generalization about the causes will work for all of the landslides because they are not the same. Each landslide is unique.
- There is much that scientists, engineers, and others do not understand about the landslides along the White Bluffs. After reading the reports over the years, some people have assumed that enough information is known about landslides to implement remedial action. More work needs to be done to understand the controls, causes, and conditions of the landslides. This is not a simple problem and there are no simple solutions.

Workshop on Impacts of Landslides on Fish and Habitat

Participants at the workshop on impacts of landslides on fish and habitat said it was difficult to answer many of the questions posed to them about impacts of the landslides, for example, to prime salmon spawning habitat. They noted that, on an anecdotal or qualitative basis, one could identify changes to the plan form of the Columbia River or to certain gravel bars where people fish or changes visible in photos taken over the years. However, the researchers did not have quantitative information about where the sediment is coming from, where it is going to, or what it is doing.

Recommendations

Based on their discussions, workshop participants agreed by consensus on the following set of recommendations (complete recommendations are found on pages 52-54 and 65):

- Do not try to mitigate landslide activity until the causes of the landslides have been determined and mitigation measures have been evaluated.
- Conduct a systematic inventory of the entire White Bluffs to lay out what is known about each landslide area.
- Conduct an engineering evaluation at the WB 10 Ponds/Wiehl Ranch landslide area.
- Initiate a more systematic, long-term monitoring network.
- Identify a single entity to compile information on activities that address landsliding along the White Bluffs.
- Coordinate efforts to avoid duplication.
- *With respect to impacts on fish and habitat*: Establish a baseline of information, now, for the future so that if there were a catastrophic increase in landslide activity, there would be data for comparison.
- Establish an ongoing dialogue about the White Bluffs landslides.
- Provide opportunities for researchers working on the landslides, the river, and fish habitat to share information about the geomorphology and the hydrogeology of the river and how the landslides and the river interact.

Introduction

This assessment of the White Bluffs Landslides was prepared as part of an interagency agreement between the US Institute for Environmental Conflict Resolution (ECR)[1] and the US Fish and Wildlife Service (FWS) Hanford Reach National Monument. The US Department of Energy (DOE) and the US Bureau of Reclamation (USBR) joined to cooperate and support this project. The project was carried out in consultation with the Hanford Reach National Monument Federal Planning Advisory (Advisory) Committee.

The assessment was undertaken because of concerns about impacts of the landslides on the Hanford Reach National Monument. The Monument was created by Presidential Proclamation in 2000 and is managed by the FWS through agreements with DOE. To date, while some studies have discussed landslide problems in specific locations along the White Bluffs, there has not been a systematic effort to identify what is causing the landslides, what their impacts are, and to identify what, if anything, can be done to reduce the rate of the landslides and to minimize their impacts. The establishment of the Monument has created an appropriate opportunity to address the White Bluffs landslide issue.[2]

Background

Over the last 30 years, landslides (commonly referred to as slumping or sloughing) have occurred at a number of places along the White Bluffs. These majestic bluffs, which vary in height from 150 to 500 feet above the Columbia River, extend approximately 30 miles north of the Tri-Cities in south-central Washington. They line the eastern shores of the Columbia River, opposite the Hanford site, in the stretch of the Columbia known as the Hanford Reach.

Triangle Associates was retained to provide a neutral situation assessment as well as process design, facilitation, and associated support services for issues surrounding the White Bluffs landslides. (Vicki King, Senior Associate at Triangle Associates, Inc. carried out the assessment.)

The assessment process was guided by the Ad Hoc Conflict Resolution Subcommittee (Ad Hoc Subcommittee) of the Advisory Committee. The Advisory Committee was established in

1 ECR was established and funded by Congress to serve as an impartial, non-partisan institution providing professional expertise, services, and resources to parties involved in environmental, natural resource and public lands conflicts. Source: ECR Program Profile

2 County Commissioners from Benton, Franklin and Grant Counties sent a letter, dated June 9, 2001, to the Secretary of the US Dept. of Interior concerning management of the Hanford Reach National Monument. On page 3 of this letter, they noted the following: “Sloughing of the White Bluffs is still an issue that has not been addressed in earnest. We ask that Interior compile existing data, conduct whatever additional research is necessary into the causes and sources of this problem, identify the most pragmatic solution, then move forward with resolution to the issue expeditiously.” See also the article by Mike Lee, “Grower earns personal victory, but larger problem unresolved,” Tri-City Herald, November 12, 2000, pp. A1-A2, where Rich Steele, who is concerned about the impact of sedimentation on spawning

2001 by the Secretary of the US Dept. of Interior to provide advice to FWS and DOE as FWS prepares a Comprehensive Conservation Plan (CCP) for the Hanford Reach National Monument. The Ad Hoc Subcommittee identified the landslides of the White Bluffs as a significant and contentious issue for the future management of the Monument that should be addressed through an independent assessment.

Purpose of the Assessment

The primary purposes of the assessment were to:

- gain an understanding of the issues related to the landslides (the factors contributing to them and the impacts caused by them) from a very broad range of perspectives;
- review technical studies and reports on the White Bluffs landslides and summarize the findings (what is known and not known about the causes and impacts of the landslides); and
- recommend and conduct a process to facilitate progress on addressing the landslides and their impacts.

(The recommended process was a series of Technical Workshops that are described and summarized in Chapter 2.)

Work on the assessment began on April 3, 2002 when a neutral third party from Triangle Associates had an initial meeting with the Ad Hoc Subcommittee and representatives of FWS, DOE and USBR. The purpose of the meeting was to discuss the scope of the issue to be addressed in the assessment, to develop an initial list of individuals and organizations to contact for the assessment, and to identify studies and reports for background research.

Assessment Process

Interviews

To initiate the interview process, the Chair of the Advisory Committee, Jim Watts, sent a letter to individuals and organizations identified at the initial meeting on April 3 (the list was later expanded), explaining the purpose of the interviews and inviting their participation.

The neutral third party from Triangle conducted interviews between April and September, 2002, in-person and by telephone, with elected officials, representatives of agencies and tribal governments, scientists, farmers and orchardists, environmentalists, and others who reflect a wide range of perspectives concerning the landslides along the White Bluffs. *(See Appendix D for the list of those interviewed, Appendix B for the letter sent to prospective interview participants, and Appendix C for the questions used in the interviews.)* These interviews resulted in a series of questions for further exploration and discussion.

habitat in the Hanford Reach, and Shannon McDaniel, Executive Director of the South Columbia Basin Irrigation District, both talked about the desirability of finding ways to reduce the landslides.

She also collected studies, reports, and newspaper articles about the White Bluffs landslides. An annotated bibliography of sources reviewed for the assessment is found in Appendix E.

Technical Workshops

Finally, in consultation with the Ad Hoc Subcommittee, the neutral third party convened three technical workshops to address the questions that were identified through the interview process. Workshop participants were selected based on their expertise, relevant knowledge and the range of perspectives they represented. The discussions and recommendations of the Technical Workshops are summarized in Chapter 2.

Structure of the Report

The assessment report is structured as follows:

Introduction

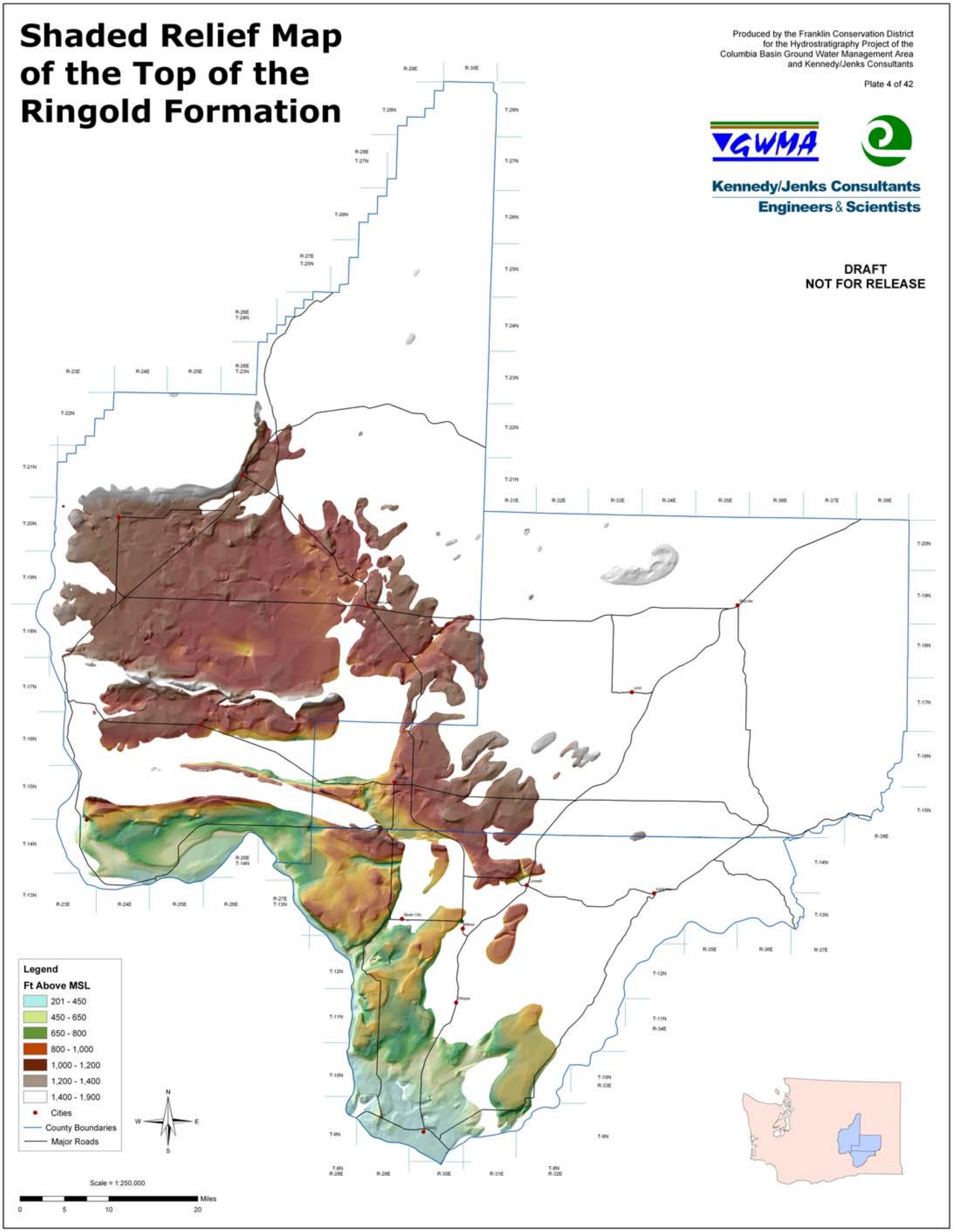
Maps

Chapter 1:
State of Information About the Causes and Impacts of the White Bluffs Landslides

Chapter 2:
Summary of Discussions and Recommendations from Technical Workshops on the Causes and Impacts of the White Bluffs Landslides

Appendices:

- A Glossary
- B Letter of invitation to participate in the assessment interviews
- C Interview questions
- D List of those interviewed
- E Annotated bibliography of studies, reports, and documents reviewed for this assessment
- F List of participants at the three technical workshops and their affiliations
- G Brief biographies of technical workshop participants


Shaded Relief Map of the Top of the Ringold Formation
Produced by the Franklin Conservation District
for the Hydrostratigraphy Project of the
Columbia Basin Ground Water Management Area
and Kennedy/Jenks Consultants
Plate 4 of 42
GWMA
Kennedy/Jenks Consultants
Engineers & Scientists
DRAFT
NOT FOR RELEASE
Legend
Ft Above MSL
201 - 450
450 - 650
650 - 800
800 - 1,000
1,000 - 1,200
1,200 - 1,400
1,400 - 1,900
Cities
County Boundaries
Major Roads
N
W
E
S
Scale = 1:250,000
0
5
10
20
Miles

Chapter One

State of Information About the Causes and Impacts of the White Bluffs Landslides

In preparing this assessment, Triangle Associates was charged with identifying what is known about issues surrounding White Bluffs landslides. The following narrative draws into one place a set of facts and opinions taken from a review of published documents about the landslides and from interviews.

Section I: Notes on Sources Concerning the White Bluffs Landslides

This section briefly describes the published information the author reviewed for the assessment. The documents include studies recommended in the interviews as well as reports found through additional research. The documents are described in three categories, by the topic they address:

- Landslides and geology
- Water and groundwater
- Fish and spawning habitat in the Columbia River

White Bluffs Landslides and Geology

The studies of the White Bluffs landslides that were used for this report were mostly prepared in the 1980s. Other than studies on the Locke Island landslide from the late 1990s, two internal memoranda prepared by WA State Department of Natural Resource (DNR) geologists in late 1996 and early 1997 on a landslide above Homestead Island and a few articles that appeared in the Tri-City Herald, the author did not find published or unpublished reports after 1989 that described or analyzed landslide activity along the White Bluffs.

Studies by Schuster, Hays, and Chleborad

The studies that cover the broadest geographic area and that are referenced by most subsequent reports were published between 1984 and 1989 by US Geological Survey (USGS) scientists – R. L. Schuster, W. H. Hays, and A. F. Chleborad. These studies characterized the geology of the White Bluffs, described the onset of landslides in multiple areas along the White Bluffs beginning in the late 1960s, and traced the evolution of those landslides up to the time the reports were published. The US Geological Survey (USGS) scientists referred to them by the names of the islands in the Columbia River they were nearest; this practice has been widely adopted. The titles of these reports, in chronological order, are as follows:

- Schuster, Robert. L. and Hays, W.H. Irrigation-Induced Landslides in Soft Rocks and Sediments along the Columbia River, South-Central Washington State, USA.

Fourth International Symposium on Landslides, Toronto 1984 Proceedings, pp. 431-436.

- Hays, William H. and Schuster, Robert L. Maps Showing Ground-Failure Hazards in the Columbia River Valley between Richland and Priest Rapids Dam, South-Central Washington, US Geological Survey. 1987 *Map A: "Generalized geologic map emphasizing ground failures and units susceptible to failure," with extensive narrative. Map B: "Active landslides, landslide-susceptible areas, and evidences of tectonic stability," with photographs of landslides.*
- Schuster, R.L., Chleborad, A.F. and Hays, W.H. Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State, 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987, pp. 147-156.
- Schuster, Robert.L., Chleborad, Alan F. and Hays, William H. The White Bluffs Landslides, South-Central Washington, in Engineering Geology in Washington, Vol. II, Washington Division of Geology and Earth Resources Bulletin 78, 1989, pp. 911-920.

Study by Marratt

In 1988, W. J. Marratt of the Franklin Conservation District published a detailed report of a landslide that he called the "Block 15" landslide. (USGS scientists referred to this same complex of landslides as the Johnson Island landslide.) The goal of Marratt's study was not only to identify the causes of the slide but also to recommend actions that could reduce landslides in the future. His report also analyzed the economic impacts of the slide.

- Marratt, W. J. Study of Landslides along the Columbia River in the Block 15 Area of Franklin County, WA, Franklin Conservation District, 1988, 26 pages with four pages of economic analysis.

Study by Neff

In 1989, George Neff, a long-time geologist with the USBR, published a 30-page article that summarized the Columbia Basin Project as a whole. This report described the geology of the region and provided a summary of the facilities that were created by the Project: the dams; the canals; the landslides (very brief section on prehistoric and recent landslides); the groundwater hydrology (geology, pre-irrigation hydrology and irrigation hydrology); drains; use of Project groundwater on non-Project land; and off-stream hydropower development.

- Neff, George E. Columbia Basin Project, in Engineering Geology in Washington. Volume I. Washington Division of Geology and Earth Resources Bulletin 78, 1989, pp. 535-563.

Memoranda by Powell and Powell

The next scientific information on White Bluffs landslides the author is aware of concerns a landslide that occurred on November 11, 1996 above Homestead Island on orchard land owned by Mr. Mel McInturf. It consists of two memoranda that were prepared .on November 20, 1996 and January 23, 1997 by two geologists (Jack Powell and Lorraine Powell) from the Washington State Department of Natural Resources (DNR). They had been asked to evaluate the November 11 landslide on Mr. McInturf's orchard land (above Homestead Island) because of potential impacts to DNR-leased land.

The first memorandum described the November 11 landslide as well as earlier landslides in the area (that had destroyed the Ringold Wasteway and the county road that provided access to Taylor Flats). The January 23, 1997 Update identified additional landslide activity that had occurred since November 11 and predicted that additional landsliding was likely.[3]

- Powell, Lorraine and Powell, Jack, Memorandum, November 20, 1996, "Landsliding in The Ringold Area" [above Homestead Island], four pages, a topographic map, and 16 pages of photographs
- Powell, Lorraine and Powell, Jack, Memorandum, January 23, 1997, "Ringold–White Bluffs Landslides – Update**,"** three pages with a topographic map marking the slides and 13 photos

Bureau of Reclamation Locke Island Landslide Study

The USBR undertook a study of the Locke Island landslide "to evaluate the ground-water conditions in the uplands above the landslide and conduct a landslide stability analysis for the Locke Island landslide." (p. ii) The Bureau initiated the study following meetings of the Locke Island Council on February 1996 and May 1997. The Locke Island Council was a multi-agency group that DOE convened to address the greatly accelerated pace of erosion of Locke Island caused by the spring runoff in 1996 that threatened valuable paleontological, Native American, cultural and historical resources on Locke Island. Prior to the study report's release, Doug Bennett (USBR geologist) briefly summarized the work he conducted on slope stability in an abstract in conference proceedings in 1999. The complete USBR Report, issued in December 2002, documented the conduct of the study and presented USBR's conclusions.

USBR concluded that the ponds created for wildlife in the late 1960s and early 1970s were located over an old channel, perpendicular to the bluff face, that was filled with glaciofluvial sediments. This channel appears to have allowed "downward vertical leakage" of water that then moved relatively quickly toward the face of the bluffs. (pp. iii-iv) USBR also concluded that "for the currently understood ground-water conditions, continued presence of the landslide debris in its present position is essential for maintaining the stability of the hillside. Without the buttressing effect of the landslide debris, the hillside is considered unstable in terms of landslide activities. Thus the erosional loss of the landslide debris to the Columbia River should be taken seriously." (p. iv) The report noted that although the slide had moved up to 80 feet between 1998 and 2002 (p. iii), landslide movement had progressively diminished after December 1997 (p. 35). The report concluded that, "Because of the presence of the Columbia River and the inevitable loss of material to erosion and scouring by the running water, small but steady, perhaps imperceptible, movements over long periods of time cannot be ruled out." (p. iv)

- Bennett, Douglas J., 1999, Locke Island landslide [abstract]: Association of Engineering Geologists, 42nd Annual Meeting, September 26-29, 1999, Program with Abstracts, p. 59.

[3] The Tri-City Herald also reported this landslide in several articles by Don McManaman, dated November 12, 1996 (Vol. 94, #317) and November 15 (Vol. 94, #320).

- Locke Island Landslide Study. White Bluffs area. Columbia Basin Project, Washington, US Bureau of Reclamation, Pacific Northwest Region, December 2002. Report prepared by Douglas J. Bennett and Dan Hubbs, Geologists under general supervision of Richard A. Link, Regional Geologist,

Other Studies

Two other studies undertaken as a result of the Locke Island Council were completed and were reviewed for this assessment. They focused specifically on the erosion of Locke Island and the impacts of that erosion.

- Locke Island Erosion Control Feasibility Study. Prepared for US DOE, Richland by Walla Walla District, Corps of Engineers, December 21, 1998.
- Nickens, P.R., Bjornstad, B.N., Cadoret, N.A., and Wright, M.K. Monitoring Bank Erosion at the Lock Island Archaeological National Register District: Summary of 1996-1997 Field Activities. Pacific Northwest National Laboratory, Richland for US DOE, August 1998.

Lindsey Study

The author also reviewed a detailed study by Kevin Lindsey of the ***geological processes that created the White Bluffs*** in the period from about 23 million years ago to just under two million years ago; this study was published in 1996. Although its focus is not specifically on landslides, this valuable report provides technical information about the specific geologic features that characterize the White Bluffs and the surrounding land. For the purposes of this assessment, the information in this study helps to explain why some areas along the Columbia River are prone to landslides and others are not.

- Lindsey, Kevin, The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-central Washington and North-central Oregon. Washington Division of Geology and Earth Resources, Open File Report 96-8, November 1996, pp. 1-45 and Appendices.

Water and Groundwater

Water, often in the form of groundwater, has been identified as a major contributor to the White Bluffs landslides in all the landslide studies reviewed for this assessment. This made scientific studies that USGS scientists conducted and reported in the 1990s on groundwater levels in Franklin County particularly helpful to this assessment.

- Drost, Brian W., Ebbert, James C., and Cox, Stephen E. Long-Term Effects of Irrigation with Imported Water on Water Levels and Water Quality. US Geological Survey (Water-Resources Investigation Report 93-4060, Tacoma, WA 1993, pp. 1-19. This report presented results for Franklin County only; the results in this report were used for this assessment. A report by USGS scientists published four years later covers a much larger geographic area. It was published as Drost, B.W., Cox, S.E., and Schurr, K.M. Changes in Ground-Water Levels and Ground-Water Budgets, from Predevelopment to 1986, in Parts of the Pasco Basin, Washington. US

Geological Survey, Water-Resources Investigations Report 96-4086, prepared in cooperation with the Washington State Department of Ecology, Tacoma, WA 1997.

Current research that should provide valuable information about groundwater flow in the White Bluffs area in the future is currently being conducted for the Columbia Basin Groundwater Management Area (GWMA). This work is being carried out in three phases. A report of work completed for the first phase is in the process of being drafted.[4]

Fish and Spawning Habitat in the Columbia River

In interviews conducted for the assessment, potential impacts of sedimentation on fish, especially on fall chinook and their habitat and spawning beds in the Columbia River, were among the most frequently identified concerns associated with the landslides. To the author's knowledge, this issue has not been systematically studied. Two reports from the 1990s addressed aspects of this issue; neither was intended to be comprehensive in scope.

- Johnson, R. L. Evaluation of Substrate Condition Near Fall Chinook Salmon (Oncorhynchus tsawytscha) Spawning Sites on the Hanford Reach, Columbia River, (Review Copy) prepared for the US Bureau of Reclamation, Pacific Northwest Laboratory, June 1994.
- Mueller, R.P., Geist, D.R. Steelhead Spawning Surveys Near Lock Island, Hanford Reach of the Columbia River, October 1999, pp. 1-11.

Because the reports and studies this assessment is based upon are not readily available to the general public, Appendix E provides brief summaries of the key findings in the documents that were reviewed for this assessment.

Section II.
Information about the White Bluffs and Landslides

A. Description of the White Bluffs

The White Bluffs are steep bluffs that extend about 30 miles along the east side of the Columbia River in south-central Washington. Located along the western boundaries of Franklin and Grant Counties, the White Bluffs begin in the south at Ringold, approximately seven miles upstream of the city of Richland. They end in the north at the "tip of the great horn" (northward bend) of the River. These majestic bluffs overlook the Hanford Site, across the Columbia River in Benton County, where nuclear materials were produced between 1943 and 1989 for national defense in production reactors that line the Columbia River. The stretch of the Columbia River these bluffs dominate is called the Hanford Reach.

[4] Personal communication from Paul Stoker, Executive Director of the Columbia Basin Groundwater Management Area, August 6, 2002.

The tops of the White Bluffs vary from 150 feet to more than 500 feet above the Columbia River.[5] Above Locke Island, the steep faces of the bluffs drop directly to the River. Further south, the bluffs step down to younger "terrace" remnants at Taylor Flat, Ringold Flat and onto the surface of moderate relief near Savage Island.

The climate of the White Bluffs area is temperate and semiarid; average annual precipitation in the area ranges from six to nine inches.

The larger geographic area that includes the White Bluffs is commonly referred to in technical reports as the Pasco Basin. In this assessment the Pasco Basin will serve as a shorthand description for the White Bluffs area that is bordered on the west by the Columbia River, that begins in the south about seven miles north of Richland and that ends about 30 miles north of Richland.[6]

B. Composition of the White Bluffs

The composition of the White Bluffs and the geologic processes that created them have been described in technical terms in several very useful studies and reports from the 1980s and 1990s.[7] In greatly simplified lay terms, the White Bluffs are made up of approximately three layers.

- The lowest or base layer consists of the Columbia River Basalt Group that is buried underneath the two layers above. This subsurface geology slopes generally toward the river.[8]
- The Ringold Formation makes up the middle layer. The Ringold Formation consists of a mix of loosely consolidated claystones, siltstones, and sandstones that lie horizontally, sloping about one degree toward the river. In some places this layer is up to 600 feet deep. The Ringold Formation can form steep natural slopes, such as

[5] William H Hays and Robert L. Schuster, Maps Showing Ground Failure Hazards in the Columbia River Valley Between Richland and Priest Rapids Dam, South-Central Washington, 1987, Map A text.

[6] See Figure 1 on p. 3 in Brian W. Drost, James C. Ebbert, , and Stephen E. Cox, Long-Term Effects of Irrigation with Imported Water on Water Levels and Water Quality. US Geological Survey (Water-Resources Investigation Report 93-4060, Tacoma, WA 1993, pp. 1-19.

[7] The sources referenced most frequently in other studies are William H Hays and Robert L. Schuster, "Maps Showing Ground Failure Hazards in the Columbia River Valley Between Richland and Priest Rapids Dam, South-Central Washington," 1987 and Robert L. Schuster, Alan F. Chleborad, and William H. Hays, US Geological Survey, "The White Bluffs Landslides, South-Central Washington, p. 911 in Engineering Geology in Washington," Volume II, Washington Division of Geology and Earth Resources Bulletin 78. Recent work by Kevin Lindsey provides detailed analysis of the geologic processes that resulted in creation of the Ringold Formation: "The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-central Washington and North-central Oregon." Washington Division of Geology and Earth Resources, Open File Report 96-8, November 1996, pp. 1-45 and Appendices.

[8] Brian Drost, James C. Ebbert, and Stephen E. Cox, "Long-Term Effects of Irrigation with Imported Water on Water Levels and Water Quality," US Geological Survey, prepared in cooperation with the Washington State Department of Ecology, Water-Resources Investigations Report, 93-4060, Tacoma, WA 1993., p. 4; personal communication, Mark Nielson, Franklin County Conservation District.

those that overlook Locke Island. The steep slopes are also a result of vertical and lateral erosion caused by the Columbia River.[9]

- The top layer consists of additional deposits of fine-grained sediments and gravel beds; these sediments are also unconsolidated, uncemented, and highly transmissive for the flow of water.[10]

C. Characteristics of the Ringold Formation that Contribute to Landslide Potential

For the purposes of this assessment, three facts about the Ringold Formation are key. First, when dry, the soft rocks of the Ringold Formation are relatively strong. However, when the clay layer is wetted, it expands and creates a barrier.[11] Second, water that reaches the barrier is trapped or "perched" and cannot easily percolate further down. Because of the slight tilt of the Ringold Formation toward the Columbia River, this perched or trapped water then flows laterally toward the face of the bluffs. The wet layer is the plane on which the slide begins. The bluff above a wet layer will slide when the water laden and lubricated layer falls under the weight of the overburden.[12] The third is that, when saturated, the soft rocks in the Ringold Formation lose much of their strength. The saturation increases pore pressures and reduces shear strength and slope stability, making the slopes susceptible to landsliding. [13]

[9] R.L., Schuster, A.F. Chleborad, and W.H. Hays, "Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State," 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987, p 148.

[10] "Background for White Bluffs – Hanford Reach, Washington." Prepared by the Nez Perce Tribe Environmental Restoration Waste Management Program, 6 pp. and a bibliography, p. 2.

[11] R.L., Schuster, A.F. Chleborad, and W.H. Hays, "Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State," 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987, p 149.

[12] Background for White Bluffs – Hanford Reach, Washington. Nez Perce Tribe ERWM, 6 pp. and a bibliography, p. 3.

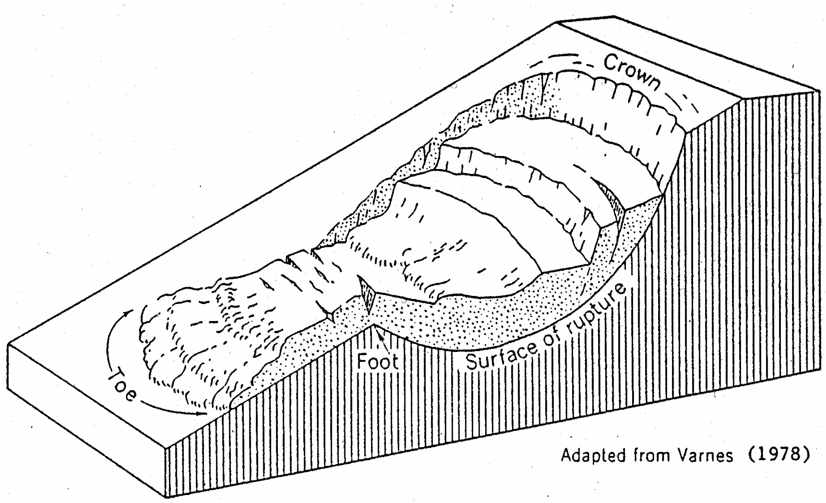
[13] R.L. Schuster and W. H. Hays, "Irrigation-Induced Landslides in Soft Rocks and Sediments along the Columbia River, South-Central Washington State, USA., 14 International Symposium on Landslides, Toronto 1984 Proceedings, Volume I, p. 431.

Table 1. The full range of land movement types identified by David Varnes[14] occurs along the White Bluffs:

Abbreviated classification of slope movements

Type of Movement		Engineering Soils	
		Predominantly coarse	Predominantly fine
Falls		Debris fall	Earth fall
Topples		Debris topple	Earth topple
Slides	Rotational	Debris slump	Earth slump
	Translational	Debris block slide	Earth block slide
Lateral Spreads		Debris spread	Earth spread

Figure 1: Typical Landslide Profile



This susceptibility is enhanced by the height, weight and steepness of the Bluffs. The steepness of the bluffs has been singled out as an important contributing cause to the landslide potential of the White Bluffs. "Based on field study of active slides," the authors of a 1989 study said, "we believe that slopes underlain by the Ringold Formation that are steeper than about 15 degrees [i.e., a 26.8 percent grade] will slide if saturated." Thus, they included on their map of landslide-susceptible areas "all areas of past and current landslide activity underlain by the Ringold Formation … even if they are less steep than 15 degrees because experience has shown that landslides in geologic materials similar to clay, silt, and sand of the Ringold Formation can reactivate on very low slopes."[15] Another study

[14] Chart adapted from David J. Varnes, "Slope Movement Types and Processes," in Landslides. Analysis and Control. Special Report 176. Robert L. Schuster, Raymond J. Krizek, Editors, Transportation Research Board Commission on Sociotechnical Systems, National Research Council, National Academy of Sciences, Washington, D.C., 1978, p. 11.

[15] William H Hays and Robert L. Schuster, "Maps Showing Ground Failure Hazards in the Columbia River Valley Between Richland and Priest Rapids Dam, South-Central Washington," 1987, Map A text. The author would like to thank Karl Fecht for providing a translation from degrees into percents.

approached the issue of slope stability from the opposite perspective – that is, what was unlikely to slide; it concluded that "slopes less than 6 percent are stable."[16]

A 1989 report described the impact of water on the Ringold Formation as follows:

> *"water [in the Ringold Formation] tends to perch in sand beds that overlie silt and clay. The formation has a very high porosity, but moderately low permeabilities impede the movement of water. Adhesive forces and wetting resistance are high. Consequently, the Ringold Formation took a long time to saturate (like a very fine sponge), but after it was saturated, it became more of a barrier to ground-water movement than an aquifer."17*

D. Characteristics of Ringold Formation Landslides

A 1987 report described the landsliding process in the Ringold Formation as follows: "The landslides generally have begun as deep-seated slump blocks; in descending the slope toward the river, they have disintegrated into thick trains of jumbled earth-flow debris."[18]

A 1989 study described the landslides in the following terms:

> *"As the Ringold Formation became wetted by the importation of irrigation water on the Columbia Basin Project lands, the wetting of steep slopes left by the channeled scabland flood erosion results in the reactivation of ancient slides and the formation of new ones. The steepest slopes slide suddenly, giving little warning. These slides are large and hazardous. Intermediate slopes fail gradually with movement occurring either on a bedding plane or as characteristic rotational failure."*[19]

A 1988 study indicated that a landslide in the Ringold Formation typically led to greater slope instability and a higher likelihood of additional landslides in the future. This was because the material was more fragmented and the wetted material that broke through removed support for the subsidence at the toe, which removed the support for the mass of broken material above.[20]

[16] George Neff, 1989 report, "Columbia Basin Project," in Engineering Geology in Washington, Vol. I, Washington Division of Geology and Earth Resources Bulletin, 78, pp. 535-563), p.553.

[17] George Neff, 1989 report, "Columbia Basin Project," in Engineering Geology in Washington, Vol. I, Washington Division of Geology and Earth Resources Bulletin, 78, pp. 535-563), pp.553-554.

[18] R.L., Schuster, A.F. Chleborad, and W.H. Hays, "Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State," 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987, p 150.

[19] George Neff, "Columbia Basin Project," in Engineering Geology in Washington. Volume I. Washington Division of Geology and Earth Resources Bulletin 78, 1989, pp. 553.

[20] W. J. Marratt, "Study of Landslides along the Columbia River in the Block 15 Area of Franklin County, WA," Franklin Conservation District, 1988, p. 12.

E. Increased Water from the Columbia Basin Project

As of the late 1980s, annual precipitation in the semi-arid lands that surround the White Bluffs averaged seven inches (over a 40-year period), with a range of 6 to 9 inches. This volume of water is too low to cause natural saturation of the White Bluffs that would cause landslides.[21] However, between 1953 and 1964 when irrigation water began to be supplied to the Pasco Basin, the Columbia Basin Project delivered the equivalent of an eight-fold annual increase in water to the area.[22] Over a 50-year period, this represents a massive increase over natural precipitation levels.

Irrigation water is provided to the area approximately six months of the year via an extensive network of canals and laterals that deliver water to fields for crop irrigation. Water flows through wasteways that take operational water (clean water that is needed to maintain a steady flow of water throughout the system) from the system and return it to the Columbia River. Storage ponds are also a part of the wasteway system.[23]

Because most of the canals, laterals, wasteways and wasteway ponds behind the White Bluffs are unlined, seeps from these various channels percolate through the soil and become recharge to groundwater.[24] In the early 1990s USGS scientists estimated that canal seepage made up about 50 percent of the groundwater recharge in a study that focused on east Benton and west Franklin Counties.[25] They further estimated that recharge from canal seepage and applied irrigation accounted for almost 90 percent of the increase in inflow to the groundwater system and the resulting rise in water levels.[26] Water table depths in the Pasco basin that had been between 300 and 600 feet before the Columbia Basin Project began delivering water soon rose. [27] Between the 1950s when irrigation began in the Pasco Basin

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21 Please see below, p. 20 for a discussion of the causes of ancient landslides..

22 R.L., Schuster, A.F. Chleborad, and W.H. Hays, "Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State," 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987, p. 148.

23 George Neff, "Columbia Basin Project," in Engineering Geology in Washington. Volume I. Washington Division of Geology and Earth Resources Bulletin 78, 1989, pp. 551-553 describes the canal and wasteway system.

24 George Neff, "Columbia Basin Project," in Engineering Geology in Washington. Volume I. Washington Division of Geology and Earth Resources Bulletin 78, 1989, p.554. "As a broad generalization, out of 6 acre ft of water diverted each year for every acre irrigated, 2 acre ft of diverted water are lost in the distribution system by seepage into the ground and operational waste, 2 acre ft are lost on the irrigated farm lands by deep percolation beyond the root depth of the crop and by surface waste, and 2 acre ft are consumptively used by the crops and associated evaporation and weed growth." Mr. Al Haymaker reported having a test conducted some years ago on the lateral that provides water to his crops; the rate of seepage was 500 gallons over 1000 feet in a 24-hour period. Personal communication, August 14, 2002.

25 J.C. Ebbert, S.E. Cox, B.W. Drost, and K.M. Schurr. Distribution and Sources of Nitrate, and Presence of Fluoride and Pesticides, in Parts of the Pasco Basin, Washington, 1986-88, U.S. Geological Survey, Water-Resources Investigations Report 93-4197, p. 1.

26 Drost, Brian W., Ebbert, James C., and Cox, Stephen E. Long-Term Effects of Irrigation with Imported Water on Water Levels and Water Quality. US Geological Survey (Water-Resources Investigation Report 93-4060, Tacoma, WA 1993, p. 13.

27 George Neff, "Columbia Basin Project," in Engineering Geology in Washington. Volume I. Washington Division of Geology and Earth Resources Bulletin 78, 1989, pp. 554. Mr. Al Haymaker recalled that the first well he had dug in 1954 was 900 feet deep; a second well, drilled about 15 years ago, hit water at 300 feet. Personal communication, August 14, 2002.

and the mid 1980s, groundwater levels rose by an average of 200 feet (with increases ranging from 100 to 500 feet). This resulted in a sevenfold increase in the annual flow through the groundwater system from pre-development time to 1986.[28]

Evidence of increased groundwater from irrigation shows up as tiered lines of vegetation on the face of the White Bluffs, as streams and ponds on landslides below the White Bluffs, and as streams in formerly dry coulees. A November 12, 2000 article in the Tri-City Herald pointed out that a wet band lined the bluffs from Johnson Island for miles to the north, showing where groundwater encountered an impermeable layer and seeped to the river. The article quoted Franklin Conservation District staff who had seen, over the previous decade, how the layers where water was coming out of the hillside had spread north, with streams forming in canyons where there had not been streams before.[29]

While irrigation from the Columbia Basin Project proceeded in much of the Pasco Basin as planned, it should be noted that some 14,000 acres of the Wahluke Slope that had been planned to be irrigated were not ultimately developed. By the mid 1960s, as a result of drainage studies the USBR conducted on the Wahluke Slope, the Bureau was aware of serious drainage problems on land that had been part of the buffer zone the Atomic Energy Commission established on the North Slope – an area referred to as the Control Zone. As a result of its studies, the USBR established a "Red Zone" around those 14,000 acres and prohibited irrigated agriculture because the cost of correcting drainage problems on those acres was not economically feasible.[30] Instead, those 14,000 acres were divided into two wildlife preserves: the federally-managed Saddle Mountain National Wildlife Refuge and the state-managed Wahluke Wildlife Refuge.

By the 1970s the USBR was also aware of potential landslide problems that higher groundwater levels could pose to those 14,000 acres, which included some of the steepest of the White Bluffs. An internal memorandum from Bureau geologist George Neff, dated May 8, 1973, described the "project experience with slides in the Ringold Formation" that resulted from the addition of groundwater and proposed "a set of empirical standards for judging slope stability." The memo advised that:

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[28] Brian W. Drost, James C. Ebbert, and Stephen E. Cox, Long-Term Effects of Irrigation with Imported Water on Water Levels and Water Quality. US Geological Survey (Water-Resources Investigation Report 93-4060, Tacoma, WA 1993, Figure 5 on p. 9 and p. 13.

[29] Mike Lee, "Grower earns personal victory, but larger problem unresolved, Tri-City Herald, November 12, 2000, pp. A1-A2.

[30] Michele S. Gerber, Ph.D. The Wahluke (North) Slope of the Hanford Site: History and Present Challenges. Westinghouse Hanford Co. Unpublished document provided by the author. In other areas, drainage problems were also soon encountered. In response the Bureau began to install an extensive drainage system to keep groundwater below the root level; the South Columbia Basin Irrigation District is now responsible for maintaining this system. Mr. Neff describes the general pace of when different types of drainage problems appear in his article, "Columbia Basin Project," in Engineering Geology in Washington. Volume I. Washington Division of Geology and Earth Resources Bulletin 78, 1989, p. 555 as follows**.** In the first 5 years of irrigation, drainage problems are usually associated with excessive distribution-system losses. Losses from laterals or canals can be reduced by lining, or drainage construction may be expedited to relieve the problem. In the second 5 years, the water table rises, and drains are needed in low-lying areas. The Project history shows that between 10 and 20 years after development, the water table becomes stabilized and that the extent to which drain construction is necessary can be finally determined, unless irrigation practices and cropping are significantly changed.

Although slope failure [in the Ringold Formation] is not consistent or universal, failure should be expected after groundwater has been added to the previously dry profile on 2:1 slopes or steeper, wherever the Ringold Formation contains clay beds underlying 30 or more feet of more permeable material. In addition, ancient slide masses on Ringold slopes can be expected to reactivate creep motion with the introduction of added groundwater. Between the south line of Section 2, T 14 N, R 26 E, and the center of Section 21, T 14 N, R 27E, the left, (north) bank of the Columbia River is very steep, being actively undercut on the outside of a bend where the course of the river makes a 180 degree change in direction. Downstream from this reach the left bank of the river rises less steeply with much of the slope blanketed with ancient landslides masses. A high potential for sudden movement of large slides exists along the 6-mile long reach of undercut bluffs if groundwater seepage significantly increases the moisture content of the formation…It must be assumed that if irrigation facilities and/or irrigation puts water into the ground in an area where a groundwater gradient would be established above this reach, the sudden movement of large slide masses into the Columbia River will eventually occur.

The memo then described, by section, township and range, the specific geographic area where "the addition of water to the ground could create a groundwater body capable of transporting water to potentially unstable strata which could result in large, sudden mass movements into the Columbia River." It concluded that "irrigation planning within this area should include consideration of the consequences of slides induced by return flows.[31]

As a result of these considerations, the USBR did not allow irrigated farming in the Red Zone.[32] However, in response to a request from the federal agency that managed the Saddle Mountain National Wildlife Refuge, the Bureau established irrigation wastewater ponds in 1969 about one mile east of the bluffs to enhance wildlife habitat.[33] There was a lag time of several years between the initial filling of the ponds and markedly increased seepage at the bluffs in late 1974 or 1975.[34] USGS scientists concluded that during the late 1970s and early

[31] Internal memorandum from George Neff to the Project Manager, dated May 8, 1973, on "Restriction of Project Development in AEC Primary Zone, two pages. The description was as follows

[32] The Wahluke Branch Canal, which formed the northern border of the Red Zone, had already been constructed and was supplying irrigation water to the Mattawa area to the west.

[33] This agency (Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Portland) sent a memorandum to the Bureau of Reclamation, dated March 10, 1970, requesting that the Bureau consider constructing and maintaining a lake of about 1,000 acres from ½ to ¾ miles back from the edge of White Bluffs to benefit wildlife. It acknowledged the Bureau's "concern for possibly contributing to the erodible condition that exists at the White Bluffs abutting the Columbia River," but also indicated that comments from the Bureau's geologist, Mr. George Neff, had led to the inference " that the surface water contributions from the lakes to this unstable condition would be comparatively minor." The memorandum noted that the Bureau of Commercial Fisheries had reviewed and concurred in the memorandum.

[34] See William H. Hays and Robert L. Schuster, Maps Showing Ground-Failure Hazards in the Columbia River Valley between Richland and Priest Rapids Dam, South-Central Washington, US Geological

1980s, seeps from irrigation wastewater channels and from these ponds were the main source of seepage water to the bluffs. (See below, pp. 18-20 for a discussion of the landslides that occurred along the White Bluffs above Locke Island.)

Section III. Landslides along the White Bluffs: Ancient and Recent

A. "Inactive" Slides, Prehistoric to Mid 1960s

There is evidence that landslides occurred along the White Bluffs in prehistoric times, within the last 11,000 years or so. However, because of the difficulty in positively identifying the origin of and in dating the landslides, there has been no comprehensive study to identify when the landslides occurred or what caused them. A leading specialist on the landslides has conjectured that these prehistoric landslides probably occurred thousands of years ago when the area climate was much wetter than at present.[35] Another specialist wrote that "several slides on the White Bluffs north and south of Ringold followed the passage of the last great flood down the Columbia, about 10,000 years ago."[36] Both reports refer to these landslides as "inactive" or ancient. Maps of inactive or ancient landslides along the White Bluffs indicate that they occurred mostly in the northern part of the White Bluffs, with a few located above Savage Island and Ringold Flat. There is also evidence of younger landslides that were probably active in the last several hundred years. Specialists believe that "toe erosion [by the Columbia River] probably was the major cause of landsliding here before irrigation water entered the picture."[37] These younger inactive slides are also found primarily in the northern part of the White Bluffs, beginning above Locke Island and ending north of the modern-day Hanford powerline.

Survey which mentions both the irrigation wastewater channels and the ponds and Schuster, Robert.L., Chleborad, Alan F. and Hays, William H. The White Bluffs Landslides, South-Central Washington, in Engineering Geology in Washington, Vol. II, Washington Division of Geology and Earth Resources Bulletin 78, pp. 911-920 which implicates only the ponds as the source of water causing the landslides.

35 Personal communication from Robert L. Schuster, July 12, 2002. See William H Hays and Robert L. Schuster, "Maps Showing Ground Failure Hazards in the Columbia River Valley Between Richland and Priest Rapids Dam, South-Central Washington," 1987. George Neff ("Columbia Basin Project" report in Engineering Geology in Washington, Vol. I, Washington Division of Geology and Earth Resources Bulletin, 78, pp. 535-563), p. 553 referred to these as "ancient slides [that] resulted from the rapid erosion associated with catastrophic flood events." He contrasted them with recent slides that "were caused by the addition of irrigation water to the lands lying over the oversteepened slopes of the Ringold Formation."

36 George E. Neff, "Columbia Basin Project," in Engineering Geology in Washington. Volume I. Washington Division of Geology and Earth Resources Bulletin 78, 1989, p. 553.

37 R.L., Schuster, A.F. Chleborad, and W.H. Hays, "Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State," 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987, p. 151.

Studies of recent (post 1960s) White Bluffs landslides do not report significant landslide activity between the time European settlers arrived in the mid 19th century and the onset of the recent or "active" landslides in the late 1960s.[38]

B. Active Slides Since the Late 1960s

"Active" landslide activity along the White Bluffs began in the late 1960s. Most observers attribute the onset of landslide activity to the Columbia Basin Project that brought water for irrigation to the area between 1953 and 1964. As noted above, irrigated agriculture brought an estimated eightfold increase in water annually over natural precipitation.[39] Over time the application of the equivalent of approximately 60 inches of precipitation per year in the early years of irrigation decreased to about 40 per year because of increased irrigation efficiency.[40] A significant portion of this water became recharge to groundwater, which caused water table levels to rise.[41] As noted above, after Columbia Basin Project irrigation began, groundwater table levels rose on average 200 feet,[42] and recharge from canal seepage and applied irrigation accounted for almost 90 percent of the increase in inflow to the groundwater system and the rise in water levels.[43] Over time, the elevated groundwater levels "caused saturation, increased pore pressures, reduced shear strength, and diminished stability of slopes above the River."[44]

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38 While the land on the bluffs was not sliding, it is not clear how stable it was. Mel McInturf, a long-time resident of the area, recalled crossing the high bluffs on horseback as a young man in the1930s and having to detour around large cracks in the earth's surface. Personal communication, August 14, 2002.

39 W. Marratt, " Study of Landslides along the Columbia River in the Block 15 Area of Franklin County, WA," Franklin Conservation District, 1988, p. 4. Another study estimated that a sevenfold increase had occurred in the annual flow through the groundwater system from pre-development time to 1986. See Drost, Brian W., Ebbert, James C., and Cox, Stephen E. Long-Term Effects of Irrigation with Imported Water on Water Levels and Water Quality. US Geological Survey (Water-Resources Investigation Report 93-4060, Tacoma, WA 1993, p. 13.

40 W. Marratt, " Study of Landslides along the Columbia River in the Block 15 Area of Franklin County, WA," Franklin Conservation District, 1988, p. 4.

41 George Neff's 1989 report on the Columbia Basin Project provided the following estimate of how water diverted for irrigation was used. "Out of 6 acre ft of water diverted each year for every acre irrigated, 2 acre ft of diverted water are lost in the distribution system by seepage into the ground and operational waste, 2 acre ft are lost on the irrigated farm lands by deep percolation beyond the root depth of the crop and by surface waste, and 2 acre ft are consumptively used by the crops and associated evaporation and weed growth. This estimate indicates that a very large amount of water became recharge to groundwater. See George Neff, "Columbia Basin Project," in Engineering Geology in Washington. Volume I. Washington Division of Geology and Earth Resources Bulletin 78, 1989, p.554.

42 Brian W Drost,. James C., Ebbert, and Stephen E. Cox,, "Long-Term Effects of Irrigation with Imported Water on Water Levels and Water Quality." US Geological Survey. Water-Resources Investigation Report 93-4060, Tacoma, WA 1993, p. 9.

43 Brian W. Drost, James C. Ebbert, and Stephen E. Cox, Long-Term Effects of Irrigation with Imported Water on Water Levels and Water Quality. US Geological Survey (Water-Resources Investigation Report 93-4060, Tacoma, WA 1993, p. 13.

44 R.L., Schuster, A.F. Chleborad, and W.H. Hays, "Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State," 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987, p. 149.

After a lag time of several years from the introduction of irrigation water, landslides began to occur.[45] The first landslides of the late 1960s were soon joined by landslides in additional areas in the1970s, 1980s, and 1990s, on both publicly and privately-owned lands. As of the mid 1980s one study estimated that the total area of sliding was more than 6.7 square miles; of this total, 20% were "active" slides. This study also reported that there were about 50 active slides with a total length of about 17 kilometers. Fourteen had surface areas exceeding 10,000 square meters each.[46] The author is unaware of more recent estimates of the extent of landslide-impacted areas.

Landslides continue to occur above the Columbia River on a smaller scale today at a number of areas along the White Bluffs. These landslides are in addition to those that have occurred inland from the River to the east where the soils and geology are similar to those of the White Bluffs.[47] Landslides in the latter locations are not the focus of this assessment.

C. Recent Landslide Activity by Area

Using the USGS convention of naming landslides along the White Bluffs, this report refers to the major landslides by the islands in the Columbia River that are near the landslides rather than by the river-mile location. From south to north, landslides have occurred in the vicinity of:

- Johnson Island (Block 15 landslide)
- Homestead Island
- Savage Island
- Locke Island

Another area where landslide activity has occurred is to the west of the Wahluke Branch or WB 10 Pond, near the Franklin-Grant County line. This landslide area has also been called the Wiehl Ranch landslide.[48] In this report, this complex of slides will be referred to as WB 10 Pond/Wiehl Ranch landslide.

The landslides are described below chronologically, based on when they became active. The descriptions include the approximate locations, estimated causes, and the general course of the landslides.

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45 George Neff, "Columbia Basin Project," in Engineering Geology in Washington. Volume I. Washington Division of Geology and Earth Resources Bulletin 78, 1989, p. 554 noted that "south of Frenchman Hills, much of the land is underlain by thick Ringold Formation sediments having low vertical permeabilities and high storage capacity. In this setting it took several years of irrigation to saturate the sediments. After saturation, perched water bodies developed on horizontal barriers (aquitards), and springs emerged on hillside outcrops."

46 R. L. Schuster, A.F. Chleborad, and W.H. Hays, "Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State," 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987, p. 432..

47 The author would like to express appreciation to the Franklin Conservation District and its executive director, Mark Nielson, for providing a map that indicates areas of currently active landslides.

48 R.L., Schuster, A.F. Chleborad, and W.H. Hays, Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State, 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987, p. 150

Homestead Island Landslides

In the late 1960s, landslide activity began in bluffs underlain by Ringold Formation above Homestead Island**,** about 13 miles north of Richland. The landslides in this area, nearly all of which are currently active or have been active since 1970, include a total of about 44 acres. Landslides in this area "have been caused by seepage of irrigation water from fields adjacent to the bluffs and from the Ringold Wasteway, a canal returning irrigation waste water to the Columbia River."[49] These slides destroyed a county road that was at the base of the bluffs.

This landslide also destroyed a large concrete flume carrying irrigation-system wastewater from the Ringold Wasteway to the river.[50] A 1989 report of this landslide concluded that the Ringold Wasteway had been located on the southern edge of an ancient landslide that became reactivated as soon as seepage from the approach channel and irrigation activity saturated the previously dry sediments. It noted that attempts to control the earth movement by installation of drainage works had been unsuccessful, and the slide destroyed the flume.[51] In 1996 geologists from DNR reported that, as a result of the previous landslide, the USBR had dammed the Ringold Wasteway 1500 feet back from the cliff. The site of the former Ringold Wasteway had become an unstable hummocky area where numerous seeps had produced abundant pockets of vegetation and small, recent slumps had developed on the surface of the older slide."[52]

On November 11, 1996 another landslide above Homestead Island destroyed orchard land that belonged to Mr. Mel McInturf.[53] Geologists from DNR who visited the site nine days after the landslide occurred indicated that a section of cliff 360 feet long and over 100 feet high had failed, forming multiple rotational slump blocks and earth flows that damaged cherry orchards that were growing on a bench below the failure. They noted that "a slide nearly as large as the present failure" was located to the south of the November 1996 flow. It had occurred in 1995 "with debris from one lobe traveling down slope to the Columbia River, crossing and partially blocking the easternmost channel, depositing material on Homestead Island."[54] They surmised that the "failure was probably along unconsolidated sand beds overlaying an impermeable clay layer."[55] They also described other, smaller landslides in the nearby vicinity. They felt it was likely that landslides would continue to occur in the foreseeable future, "impacting the Columbia

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49 See William H Hays and Robert L. Schuster, "Maps Showing Ground Failure Hazards in the Columbia River Valley Between Richland and Priest Rapids Dam, South-Central Washington," 1987, Map A text.

50 See William H Hays and Robert L. Schuster, "Maps Showing Ground Failure Hazards in the Columbia River Valley Between Richland and Priest Rapids Dam, South-Central Washington," 1987, Map A text. The researchers concluded that there was a "low probability that a slide could block the channel between the slide and Locke Island and an "extremely low probability that a slide could block the main channel southwest of Locke Island."

51 George Neff, "Columbia Basin Project:" in Engineering Geology in Washington, Vol. I, Washington Division of Geology and Earth Resources Bulletin, 78, pp. 535-563) p. 551

52 Lorraine Powell and Jack Powell, Memorandum, November 20, 1996, "Landsliding in The Ringold Area" [above Homestead Island], p. 3.

53 Damage to Mr. McInturf's orchard land was described in several articles in the Tri-City Herald, written by Don McManaman, dated November 12 (Vol. 94, #317) and November 15 (Vol. 94, #320).

54 Lorraine Powell and Jack Powell, Memorandum, November 20, 1996, "Landsliding in The Ringold Area" [above Homestead Island], p. 2.

55 Lorraine Powell and Jack Powell, Memorandum, November 20, 1996, "Landsliding in The Ringold Area" [above Homestead Island], p. 3.

River and hindering development." [56] During a second site visit two months later they found the slope "actively moving at the toes of previous landslides, small mud slides were actively undermining slopes, and large areas of the slope [were] cracked and bulged."[57] Mr. McInturf who irrigates his crops with water taken directly from the Columbia River (not with Columbia Basin Project irrigation water) believes the landslide was the result of unlined canals from the Columbia Basin Project.[58]

Savage Island Landslides

In the late 1960s, significant landslide activity also began above Savage Island**,** about 18 miles north of Richland. As of the late 1980s these landslides were second only to Locke Island in size and degree of activity.[59] A 1989 report indicated that this landslide affected about 120 hectares (about 300 acres). About 40 per cent of this was a continuous landslide mass, with a volume of about ten million cubic meters of material that became active after 1968 and had "enlarged dramatically" after 1980 and continued as of the report completion.[60] The authors attributed the landslides to "irrigation of fields east of the bluffs, both adjacent to the retreating head scarp and farther east."[61] They noted that landslide activity had been greatest in the spring of the year when the combination of irrigation water and residual moisture from winter precipitation created a critical soil-moisture relationship. Seepage from the landslide and the head scarp was forming small creeks that ponded on the landslide and at its toe. In April 1983, flow from springs on the landslide was estimated at 70 cu m/hr.[62] Erosion by the Columbia was determined not to be a factor in these landslides because the White Bluffs are set back from the River above Savage Island. This setback from the River also means that debris from the Savage Island landslides does not reach the Columbia River, in contrast to the other landslides described here.[63] The authors concluded that the only economic loss from the landslide had been the destruction of about 4 hectares (around 10 acres) of prime cropland by encroachment of the head scarp. However, they speculated that if irrigation continued on the upland adjacent to the landslide, landslide encroachment could be expected to continue.[64] The

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[56] Lorraine Powell and Jack Powell, Memorandum, November 20, 1996, "Landsliding in The Ringold Area" [above Homestead Island], p. 3.

[57] Lorraine Powell and Jack Powell, Memorandum, January 23, 1997, "Ringold–White Bluffs Landslides – Update, p. 1.

[58] Personal communication from Mr. McInturf, August 14, 2002.

[59] R.L. Schuster and W.H. Hays, "The White Bluffs Landslides, South-Central Washington," in Engineering Geology in Washington, Vol. II, Washington Division of Geology and Earth Resources Bulletin 78, pp. 911-920, p. 916.

[60] R.L. Schuster and W.H. Hays, "The White Bluffs Landslides, South-Central Washington," in Engineering Geology in Washington, Vol. II, Washington Division of Geology and Earth Resources Bulletin 78, pp. 911-920, p. 916.

[61] Schuster, Robert. L. and Hays, W.H. Irrigation-Induced Landslides in Soft Rocks and Sediments along the Columbia River, South-Central Washington state, USA. Fourth International Symposium on Landslides, Toronto 1984 Proceedings, pp. 435-436.

[62] R.L. Schuster and W.H. Hays, "The White Bluffs Landslides, South-Central Washington," in Engineering Geology in Washington, Vol. II, Washington Division of Geology and Earth Resources Bulletin 78, pp. 911-920, p. 916.

[63] R.L. Schuster and W.H. Hays, "The White Bluffs Landslides, South-Central Washington," in Engineering Geology in Washington, Vol. II, Washington Division of Geology and Earth Resources Bulletin 78, pp. 911-920, p. 916.

[64] R.L. Schuster and W.H. Hays, "The White Bluffs Landslides, South-Central Washington," in Engineering Geology in Washington, Vol. II, Washington Division of Geology and Earth Resources Bulletin 78, pp. 911-920, p. 917.

authors also noted that large tension cracks extending from both ends of the head scarp indicated potential for the landslide mass to extend north and south along the bluff.[65]

Johnson Island Landslides

In the late 1960s, the Johnson Island area also began to experience landslides. A 1988 study of this landslide said that it had developed over a 19-year period on the west side of irrigation Block 15. [66] In 1969, a small slump block caused a noticeable scarp just west of the center of farm unit 187. By 1971, the slide had enlarged and showed three scarps and their associated slump blocks. By 1973, the toe of the original slide had formed a mudflow that breached the county road at the bottom of the bluffs for the first time and flowed into the Columbia River. In 1979, a major landslide destroyed 28 acres of orchard land belonging to Mr. Al Haymaker. The landslide occurred with such force that slide debris flowed across the river channel and onto Johnson Island, contributing a significant amount of sediment to the River.[67] Mr. Haymaker believes that the landslide was caused by seeps from an unlined lateral that provides irrigation water to his fields.[68]

Up to 1979 closures of the county road were common because of mud and debris flowing from the enlarging slide area. By 1979, there was evidence that nearly a mile of the bluff was involved in sliding, and the toe of one portion of the slide area covered the road to a depth of 30 to 40 feet for more than 100 feet. As of the study publication (1988), the road was permanently closed. By the latter 1980s, there was evidence of sliding in an area more than 6,600 feet along the bluffs that involved approximately 3.5 to 4 million cubic yards of material. These slides occurred on the steepest portions of the bluff (25 to 28 degrees).

This study concluded that the slides were caused by three factors:

1. <u>Active erosion of the toe of the slide by the Columbia River.</u> It noted that while the River had been undercutting the bluffs and causing landslides for tens of thousands of years, the type of landslides such undercutting typically caused – earth falls -- was different from the "slump-earth flow landslides that were now developing since the addition of water."
2. <u>The composition of the White Bluffs (Ringold Formation, discussed above, pp. 7-9).</u> The author described the geologic composition of the bluffs in the Block 15 area: the upper, more permeable layer that ranged in depth from about 450 feet above the river to the top of the bluff at about 870 to 890 feet and the middle layer which ranged from 285 to about 450 feet above the River and acted as a barrier to further downward water movement. As a result of these conditions, water could travel horizontally in the sandstones that directly overlie the more impermeable layers. He

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65 William H Hays and Robert L. Schuster, "Maps Showing Ground Failure Hazards in the Columbia River Valley Between Richland and Priest Rapids Dam, South-Central Washington," 1987. Map A text.

66 W. J. Marratt, " Study of Landslides along the Columbia River in the Block 15 Area of Franklin County, WA," Franklin Conservation District, 1988 is the source of this account.

67 Personal communication from Mr. Haymaker, August 14, 2002.

68 Personal communication from Mr. Haymaker, August 14, 2002. This landslide was discussed in an article by Mike Lee in the Tri-City Herald dated November 12, 2000. The article reported that the South Columbia Basin Irrigation District had agreed to line the lateral (small irrigation canal) that runs past his orchard, "the conclusion of a 30-year old dispute." The District indicated that the work was part of ongoing maintenance of the system.

said that field observations confirmed that water was indeed flowing from the bluffs at about the 600-foot and 700-foot elevations, and at or near the contact between the thicker sand layers and the underlying [impermeable] silt or mudstone level. He pointed out that while the material making up the White Bluffs was "fairly resistant to erosion as long as it remains dry" and the overlying layers are not breached, the same material has little or no structure strength if water penetrates the cap or if it is saturated from below. When either occurs, "this same material has little or no structure strength and fails, slumps, and flows, forming a typical landslide profile.

3. <u>A dramatic increase in the amount of water as a result of the Columbia Basin project.</u> The author described two possible sources of the water: greatly elevated groundwater levels as a result of the Columbia Basin Project or a "perched water table of regional proportions." The water springing from the bluffs at about the 600 and the 700 foot levels seemed to give weight to the perched water table explanation.

As of 1988 (the study publication date), the author considered the slide to be "very hazardous" with the potential to cause about 150 acres of agricultural land to be lost at the top of the bluff.[69] The author also noted that water running through the slide debris was flowing into the Columbia River carrying silt, nitrates, and possibly other contaminants. In September of 1987, the sediment flow into the River was 31 tons per day, which was silting the "once gravel bottom of the river" downstream from the landslide" and possibly damaging fisheries and other fragile ecosystems.[70]

As noted above, between 1973 and 1983 successive landslides above Johnson Island completely destroyed a county road that ran along the base of the bluffs providing access to Taylor Flats.

Locke Island Landslides

Further upriver, sloughing of sediments started in the late 1970s and expanded to create the largest landslide complex along the White Bluffs in an area across the channel from Locke Island. This area of the White Bluffs is being actively undercut by the Columbia River as the river bends from an easterly flow direction to southeasterly flow along the front of the bluffs. Over the millennia, erosion by the river has created some of the steepest terrain along the bluffs; in places it ranges up to about 45 degrees.[71] After landslide activity began in the late 1970s, it grew in intensity in the early 1980s and peaked in 1985. A study of these landslides concluded that seeps from irrigation wastewater ponds established within two kilometers of the river to enhance wildlife habitat during the late 1970s and early 1980s were a major cause of the failure of the

69 W. J. Marratt, " Study of Landslides along the Columbia River in the Block 15 Area of Franklin County, WA," Franklin Conservation District, 1988 , p. 6.

69 W. J. Marratt, " Study of Landslides along the Columbia River in the Block 15 Area of Franklin County, WA," Franklin Conservation District, 1988 , p. 6.

70 W. J. Marratt, " Study of Landslides along the Columbia River in the Block 15 Area of Franklin County, WA," Franklin Conservation District, 1988 , p. 13.

70 W. J. Marratt, " Study of Landslides along the Columbia River in the Block 15 Area of Franklin County, WA," Franklin Conservation District, 1988, p. 13.

71 The author would like to thank Karl Fecht for this slope conversion; personal communication, October 14, 2002.

slopes above the river. [72] The seeps were the result of water from the ponds that migrated downward into sandy soils and then moved laterally toward the bluff face along the contact of a relatively impervious mud unit. The two primary controls on water movement above Locke Island appear to be the impervious mud unit that limits movement vertically and an old channel, eroded into the top of the bluffs and later filled with sandy sediments, that forms a preferential pathway laterally toward the bluffs.[73] Water along the face of the White Bluffs began forming visible wetting fronts of damp sediments between the sandy soils and the mud unit. Eventually, the water content along the bluff face was sufficient to increase the pore pressure in the sedimentary sequence and reduce the material strength causing gravitation slope failure and formation of landslides. A recent report estimated that the Locke Island landslide had displaced about 30 million cubic yards of material.[74]

Although the landslide activity at Locke Island is thought to have peaked in the mid 1980s, landslide activity above Locke Island continues, although on a smaller scale. [75] This continued landslide activity has narrowed the channel between Locke Island and the mainland by two-thirds (from roughly 450 meters in the early 1970s to 150 meters in 1996). The narrowed channel has caused flows to the east of Locke Island to speed up which, in turn, has caused significant erosion along the eastern shore of Locke Island. Erosion was particularly acute during the high flow years of 1996 and 1997. The erosion exposed cultural resources, raising serious concerns about damage and loss of invaluable paleontological, Native American, cultural and historical resources located on the island.[76]

A brief summary report of work on slope stability conducted by the USBR in the late 1990s indicated the following: "Investigations concluded that surface water moves vertically through overlying Holocene silts and sands until encountering impermeable clay units of the Pliocene Ringold Formation, where the water moves horizontally resulting in conditions favorable to landsliding. Continued movement can be attributed to toe erosion and head scarp saturation. Although the addition of water above the bluffs appears to have increased landslide activity, historically landslides have occurred before the introduction of irrigation water. The diverted water into the ponds [created behind the bluffs to enhance wildlife habitat] has accelerated a natural, ongoing condition along the White Bluffs."[77]

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[72] R.L., Schuster, A.F. Chleborad, and W.H. Hays, "Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State," 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987, p 150.

[73] The author would like to thank Karl Fecht, Bechtel Hanford, for information about the presence of the old river channel (also referred to as a paleo channel) above the Locke Island landslide that appears to have facilitated the downward movement of water from the ponds to the relatively impervious layer below and from there to the face of the bluffs. Communications from Mr. Fecht on August 14 and October 14.

[74] Douglas J.Bennett, 1999, Locke Island landslide [abstract]: Association of Engineering Geologists, 42nd Annual Meeting, September 26-29, 1999, Program with Abstracts, p. 59.

[75] In the mid 1990s FWS fisheries biologist Don Anglin discovered continuing landslide activity above Locke Island that was sending large amounts of sediment into the River and narrowing the channel east of Locke Island in the course of conducting a study related to white sturgeon in the Columbia River below Priest Rapids Dam. Personal communication, October 9, 2002.

[76] See P.R. Nickens, B.N Bjornstad,. N.A. Cadoret, and M.K. Wright, "Monitoring Bank Erosion at the Lock Island Archaeological National Register District: Summary of 1996-1997 Field Activities." Pacific Northwest National Laboratory, Richland for US DOE, August 1998.

[77] Douglas J. Bennett, 1999, Locke Island landslide [abstract]: Association of Engineering Geologists, 42nd Annual Meeting, September 26-29, 1999, Program with Abstracts, p. 59.

WB 10 Ponds/Wiehl Ranch Landslides

In the early 1980s, landslides began occurring a few kilometers south of Locke Island, in an area variously designated as the WB 10 Pond landslide area or the Wiehl Ranch landslide area. A 1987 report indicated that a wastewater pond about three kilometers east of the river was contributing to seepage and to new landslide activity along the White Bluffs in this area.[78] As of a 1989 report, the landslides in this area were not yet large enough to flow into the river, but the report authors projected that "until irrigation-water seepage from the east into the bluffs is stopped, landslide activity would probably continue along this stretch of the river."[79] Some members of the agricultural community believe seeps from the WB 10 Ponds could be a significant cause of these landslides. If investigations show that the ponds contribute to the landslides, they favor draining the ponds.[80]

As noted above, the author is unaware of systematic, scientific work investigating landslide activity along the White Bluffs since the end of the 1980s. However, landslides are a continuing concern, and often an active reality, in all of the areas described above.[81]

Section IV.
Impacts of the White Bluffs Landslides

Several studies by USGS scientists from the 1980s mentioned that the direct economic losses caused by landslides in areas they studied had been relatively low because the areas affected by landslides had not been developed. Nonetheless, based on published reports and input from those interviewed, the White Bluffs landslides are of significant concern because, among other impacts, they have caused:

- greatly accelerated erosion along Locke Island, especially in years of high river flow, with consequent loss of paleontological, Native American, historical and archaeological resources[82];

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78 R.L. Schuster, A.F. Chleborad, and , W.H. Hays, Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State, 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987, p. 150. See also William H Hays and Robert L. Schuster, "Maps Showing Ground Failure Hazards in the Columbia River Valley Between Richland and Priest Rapids Dam, South-Central Washington," 1987. Map A text.

79 William H Hays and Robert L. Schuster, "Maps Showing Ground Failure Hazards in the Columbia River Valley Between Richland and Priest Rapids Dam, South-Central Washington," 1987. Map A text.

80 In an article by Mike Lee, "Grower earns personal victory, but larger problem unresolved, Tri-City Herald, November 12, 2000, pp. A1-A2 Shannon McDaniel, Executive Director of the South Columbia Basin Irrigation District is quoted as supporting draining standing water that could be contributing to the activity at the bluffs. He also noted that the District was doing seepage studies on the upper section of Potholes Canal and that it had drained a 40-acre pond above the White Bluffs several years previously. Congressional Representative Hastings introduced a bill in the House of Representatives (HR Bill 1031) on March 9, 1999 concerning the Wahluke Slope Habitat Management Area. Among other things, the bill proposed draining the Wahluke Branch 10 Wasteway of the Columbia Basin Project to remove all standing water above the White Bluffs. This wasteway flows westward across the center of the Wahluke Unit.

- increased sediment load to the river and deposition of fine-grained sediment that threaten the best spawning habitat for fall chinook on the Columbia River;
- damage to agricultural fields from bank failures and to property on those fields;
- damage to a concrete flume at the Ringold Wasteway;
- the closure of a Franklin County road along the base of the bluffs between Pasco and Washington State Highway 24 (north of the study area) that was buried by successive landslides (1973-1983); and
- changes to the ecosystem along the Bluffs where seeps and springs have appeared on previously dry slopes.

Those interviewed also expressed concern about potential impacts. One of these is the possibility of an increase in radionuclide contamination of the River if a major landslide in the Locke Island area were to block all or part of the River, driving river flow to the west side where nuclear production facilities and contamination are close to the River.[83] A second is possible damage from sediment to cooling-water intake systems for the Washington Public Power Supply System Reactor downriver. A third is potential damage to additional agricultural lands.

As noted above, the impacts to Locke Island have received the most recent attention.[84] Three other impacts were singled out.

1. Impacts to Fish and Spawning Beds: The studies reviewed as well those interviewed for this assessment – all expressed concern about the impact of sedimentation from the White Bluffs landslides on salmon spawning habitat and the river.

2. Impacts to Irrigated Agriculture: As noted above, some agricultural fields were lost as a result of landslides.

3. Ecological Impacts: The appearance of water at the bases and on the slopes of the formerly-dry bluffs – often in multiple tiers -- has caused a dramatic change in the vegetation along the White Bluffs.

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81 The author would like to express appreciation to The Franklin Conservation District for providing a map that identifies current "Landslide Areas Near the Hanford Reach National Monument."

82 Locke Island was listed on the National Register of Historic Places in the mid 1970s, about six years after two (of an estimated 80) pit houses were excavated. Paul Nikkens, Battelle scientist, estimated that the island was used by Native Americans for at least 2000 years. This information was noted in an article by Mike Lee in the Tri-City Herald, August 24, 1997.

83 From 1943 to 1989 facilities at the Hanford Site were built and operated primarily to produce nuclear materials for national defense; nine production reactors were built along the Hanford Reach. The groundwater at the Hanford Site is known to harbor radioactive and hazardous waste. The likelihood that a landslide (particularly in Locke Island area) could dam up the Columbia River, driving river flows to the west where the reactors and underground contamination are known to exist, was addressed in a report by Robert L. Schuster and W. H. Hays, who concluded there was a "low probability that a slide could block the channel between the slide and Locke Island and an "extremely low probability that a slide could block the main channel southwest of Locke Island." See William H Hays and Robert L. Schuster, "Maps Showing Ground Failure Hazards in the Columbia River Valley Between Richland and Priest Rapids Dam, South-Central Washington," 1987, Map A text.

84 The Locke Island Council process led to work by the Bureau of Reclamation on groundwater movement and slope stability; work by the Army Corps of Engineers on the feasibility of reducing erosion at Locke Island; and work by Battelle to assess the rate of erosion of Locke Island.

Section V.
Factors Identified as Causes of Landslides along the White Bluffs

The published reports cited above as well as most of those interviewed for this assessment have generally attributed the onset and continuation of landslide activity along the White Bluffs since the 1960s to three factors, often in combination[85]:

1. The underlying geologic composition of the White Bluffs (Ringold Formation) that makes steep slopes highly susceptible to sliding when wetted;
2. Elevated groundwater levels (as a result of seeps from canals, laterals, wasteways and wasteway ponds and from application of irrigation water) that saturate the soils of the Ringold Formation and make them susceptible to landsliding; and
3. Erosion caused by the Columbia River running against the base of the steep bluffs at Locke Island and washing away the toe of landslides, which reduces slope stability above.

[85] Two additional factors were identified during the interviews as lesser contributors to the landslides: powerboat wakes and Bank Swallow nests in the bluffs. In the Technical Workshops on Geology/Landslides (summarized in Chapter 2), participants agreed that both of these factors did not contribute to the landslides.

Chapter Two

Summary of Discussions and Recommendations from Technical Workshops on the Causes and Impacts of the White Bluffs Landslides

With the exception of the several studies conducted following severe erosion at Locke Island in 1996, there have been no systematic efforts since the late 1980s to understand or address the White Bluffs landslides, despite their obvious importance.

To update published information about the causes and impacts of the landslides (described in the previous chapter) and to respond to specific questions and issues that were raised during the interview process, the neutral third-party recommended and the Ad Hoc Subcommittee of the Advisory Committee endorsed conducting a series of technical workshops.

The purpose of the technical workshops was to bring together individuals with expertise in issues related to the White Bluffs landslides (causes and impacts) with a goal of identifying what is known about the causes and impacts of the landslides, information gaps, and potential solutions, if any.

Each workshop addressed one of the major areas of concern:

- Landslides and geology
- Water, groundwater, and irrigated agriculture
- Impacts to fish and habitat

Workshop participants included scientists and specialists who were invited based on their expertise, relevant knowledge and the range of perspectives they represented.[86] Along with a process facilitator for each session, a technical facilitator moderated the sessions on geology/landslides and water/groundwater.[87] The list of participants at each workshop is included at the beginning of the individual workshop summary; it is also included in Appendix F.

The technical workshops were held as follows:

- Geology/Landslides, Tuesday, January 21, 2003, 1:00 PM to 5:00 PM
- Water/Groundwater/Irrigated Agriculture, Wednesday, January 22, 2003, 1:00 PM to 5:00 PM
- Fish and Spawning Habitat, Thursday, January 23, 2003, 1:00 PM to 4:00 PM

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[86] Brief biographies of the participants in the technical workshops are found in Appendix G.

[87] The technical facilitator of the workshop on fish and spawning habitat was unable to attend because of illness.

All three technical workshops were held at the Consolidated Information Center on the Washington State University Campus in Richland.

In advance of the technical workshops, invited participants received copies of the draft summary of published information and a set of questions/issues raised during the interviews. These initial questions/issues were revised both in advance and during the workshops to make the discussions more productive.

Following the workshops, the neutral third party prepared a draft summary of each workshop and sent it to the participants to review and revise. The summaries that follow incorporate their revisions. In a number of cases, participant comments on the summary are presented in footnotes, identified as "Reviewer's Comments."

Each workshop summary has a similar format.

- Workshop participants and the questions/topics they discussed are identified at the beginning of the summary.
- The key points from the discussion and conclusions concerning each question/issue are summarized next.
- The set of recommendations from the workshop conclude the summary.

Section I:
Combined Summary of Workshop Discussions on Geology and Landslides and Water, Groundwater, and Irrigated Agriculture

At the request of the participants in the Technical Workshops on Geology and Landslides and on Water, Groundwater, and Irrigated Agriculture (conducted on separate days but with many of the same participants), the summaries of their discussions have been combined because the issues are inextricably intertwined and to minimize redundancy. The six specialists who participated in both workshops are identified directly below. The specialists who participated in one workshop are identified separately.

In the summary that follows, questions and issues related to geology and landslides are, in general, presented first. Discussions related to geologic and groundwater contributions to landslides are second, followed by discussions that relate primarily to water, groundwater, and irrigated agriculture.

Participants

Name	Affiliation
Participants at Both Workshops	
Robert L. Schuster ***(Technical Facilitator)***	U.S. Geological Survey Scientist Emeritus (volunteer, retired)–Landslide specialist, Denver, CO
Douglas Bennett	Engineering Geologist, U.S. Bureau of Reclamation, Boise, ID
Kayti Didricksen	Hydrogeologist, U.S. Bureau of Reclamation, Grand Coulee, WA
Dan Hubbs	Geologist, U.S. Bureau of Reclamation, Ephrata, WA
Kevin Lindsey	Geologist, Kennedy-Jenks Consultants, Kennewick, WA
Shannon McDaniel	Manager, South Columbia Basin Irrigation District, Pasco, WA (Observer at the Workshop on Geology/Landslides; Participant at the Workshop on Water/Groundwater/Irrigated Agriculture)
Mark Nielson	Franklin Conservation District Manager, Pasco, WA
Additional Participants at the Workshop on Geology/Landslides	
Rex Baum	Landslide expert for the U.S. Geological Survey, Denver, CO
Karl Fecht	Geologist at Bechtel-Hanford, Richland, WA
Additional Participants at the Workshop on Water/Groundwater/Irrigated Agriculture	
Steve Cox	Hydrologist, U.S. Geological Survey, Tacoma, WA
Paul Stoker	Executive Director, Columbia Basin Groundwater Management Area, Othello, WA

Questions Discussed

1. (a) How should the geographic area of the White Bluffs be defined for the purposes of this workshop?
   (b) What is the area behind the White Bluffs that controls or influences landsliding on the bluffs?
2. Is there adequate information about the underlying geology (including seismicity) of the surrounding land (up to 20 miles to the east and northeast) to characterize the landslide hazards?
3. What kinds of landslides occur along the White Bluffs?
4. (a) What is known about how groundwater moves to and through the White Bluffs?
   (b) How could one best track groundwater flow in and through the White Bluffs?
5. Do elevated groundwater levels contribute to landslides of the White Bluffs? If so, how?
6. What does monitoring show about trends in groundwater levels? Are they stable, rising, or falling?
7. What are the geologic controls for entry of groundwater and the groundwater sources that contribute to landslides at the following locations:
   (a) Locke Island;
   (b) Savage Island;
   (c) Homestead Island;
   (d) Johnson Island;

(e) West of the WB 10 Pond/Wiehl Ranch; and
(f) Any other areas of concern?

8. Is the water problem that contributes to the landslides above Locke Island a case of "perched water" from ponds that were created in the late 1960s and now dry or is it a case of elevated groundwater levels that have saturated the soil column?
9. What effect, if any, does irrigation have on groundwater movement at the Locke Island landslide and on the WB 10 Pond/Wiehl Ranch landslide?
10. What are the similarities and differences in the causes of landslides at Locke Island, Savage Island, Homestead Island, Johnson Island and west of the WB 10 Pond/Wiehl Ranch?
11. Are there identified areas in the White Bluffs that are more susceptible to landslides than others?
12. Are there areas between Locke Island and Johnson Island that have not experienced landslides that can be expected to experience them in the future? If so, which ones and why? What about south of Johnson Island?
13. What sets of factors contribute to the landslides of the White Bluffs?
14. What impact have fluctuations (annual and daily) had on erosion and sedimentation in the river? Have erosion and sedimentation rates changed with time?
15. Are river-level fluctuations from power generation causing a problem?
16. Are there potential safety concerns associated with the landslides?
17. Can areas where landslides have occurred be prioritized in terms of risk?
18. What contribution, if any, do agricultural practices make to the landslides through groundwater recharge?
19. Are lined facilities (e.g., the Wahluke Branch Canal) monitored to see if water seeps from them to the ground below? If so, what are the results? Are unlined facilities monitored to see if water seeps from them to the ground below? If so, what are the results?
20. Why are some canals lined and others are not, and what does being lined or unlined mean for groundwater recharge?
21. What differences are new irrigation techniques making in the quantities of water used for irrigation and in quantities of water that become recharge to groundwater? How widespread is the use of the new techniques?
22. Does water from the Snake River impact the groundwater in the Pasco Basin?
23. What has been the impact of the White Bluffs landslides on agriculture?
24. What is the effect of rainfall in the White Bluffs area on groundwater hydrology?

Workshop Discussion Summary

For the reader's convenience, a map showing recent landslide activity along the White Bluffs and a map showing the extent of the Ringold Formation are located at the beginning of Chapter 1.[88]

Question 1a: How should the geographic area of the White Bluffs be defined for the purposes of this workshop?

Conclusions

- For the purposes of this workshop, the White Bluffs as a geomorphic entity extend along the Columbia River from Johnson Island in the south to the Horn of the Columbia River in the north. The White Bluffs expose a thick sequence of Pliocene-Miocene age sediments of the Ringold Formation. The Ringold Formation underlies the bluffs and covers a much more extensive area than the geomorphic expression of the White Bluffs. (See 1.b. below.)

Question 1b: What is the area behind the White Bluffs that controls or influences landslides on the bluffs?

Key Points from the Discussion

- The question involves both groundwater and geology. From a groundwater perspective, it is not clear how far from the east groundwater can influence the White Bluffs; it depends on the travel time for the groundwater and the existence of a hydraulic connection between the bluffs and any potential source area and those are not known. Geologic controls for landsliding along the White Bluffs are primarily associated with the Ringold Formation. The Ringold Formation dies out around SR 395 to the east and southern flank of Saddle Mountain. The bedding in the Ringold Formation dips slightly (about 1^{o}) towards the Columbia River.

Question 2: Is there adequate information about the underlying geology, including seismicity of the surrounding land (up to 20 miles to the east and northeast) to characterize the landslide hazards?

Key Points from the Discussion

- The unanimous answer by the workshop participants is that there is not adequate information about the underlying geology. If sufficient water is added to the fine-grained sediments of the Ringold Formation at the steep face of the White Bluffs, slope failure occurs in the form of landslides. However, the specific mechanisms and processes that form landslides along the bluffs are not known. There are not enough data to explain these results or to predict future landslide activity.

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88 The author would like to thank the Franklin Conservation District for these maps.

- Some areas along the White Bluffs have water running down the bluff face but do not display any significant signs of slumping. Some areas maintain slope stability due to the highly cemented nature of the Ringold material or younger sediments filling Ringold and Kootnz Coulees. There are other “non slumping areas” along the White Bluffs with running water in which the mechanisms for groundwater flow and slope stability are not understood.
- Prehistoric landslides have been observed and mapped along the White Bluffs. Some prehistoric landslides are a result of undercutting of the White Bluffs by the Columbia River or ice-age floods. The mechanisms and processes that formed other prehistoric landslides are not known. There has been no systematic detailed study of prehistoric landslides along the White Bluffs.
- Sedimentary beds within the Ringold Formation display highly variable textures and grain sizes. This variability will affect groundwater travel time through the Ringold units. Groundwater movement through the Ringold sediments is not fully understood.

Conclusions

- More information on the stratigraphy and sedimentary structures of the underlying geology that control groundwater flow is needed to explain existing landslides and associated hazards.
- Seismicity is not considered to be a key geologic process to the formation of landslides on the White Bluffs.[89]

Question 3: What types of landslides occur along the White Bluffs?[90]

Key Points from the Discussion

- There clearly are very old or prehistoric landslides. In places prehistoric landslides have occurred right next to a new landslide on the bluff. In aerial photos, one can distinguish the prehistoric from new landslides. Prehistoric landslides have been mapped and included in published reports[91] but have not been the subject of detailed studies. Insight into the causes of the prehistoric landslides could be developed with some future studies.
- It would be worthwhile to study the landslides because there will be questions about their origin; it would be helpful to identify which landslides are a result of man’s activities and which are not. The results of such a study could possibly provide insight into predicting future mass wasting events along the White Bluffs.

89 Reviewer’s Comment: Clearly seismicity is not a key factor in causing recent slides; however, seismicity cannot be ruled out as a mechanism for causing prehistoric slides or for activating new slides.

90 See Chapter 1, p. 8 for a chart identifying the types of landslides that geologists have identified and a schematic of the landslide type that typically occurs along the White Bluffs.

91 William H. Hays and Robert L. Schuster, Maps Showing Ground-Failure Hazards in the Columbia River Valley between Richland and Priest Rapids Dam, South-Central Washington, US Geological Survey. 1987

Question 4a: What is known about how groundwater moves to and through the White Bluffs?

Key Points from the Discussion

- With respect to the landslides, this is generally a Ringold Formation issue. There are three major sediment types: the conglomerates, interbedded river-deposited sand and paleosols, and lacustrine lake deposits. Water moves through each unit differently. Understanding water movement through the conglomerates is not important for landslides because there are no known failures in the conglomerate unit. Preferred flow pathways are related to the coarser materials found in the unconsolidated portions of the Ringold Formation.

- It is known that facies[92] distribution provides pathways that control groundwater movement, but for the Ringold Formation these details are not known. If one looks at the finer-grained material that is more susceptible to sliding, one finds interbedded layers of silt, clay, and sand. The sand layers will hold or move water. It is necessary to understand the depositional patterns to see where the water will perch and build up and where it will flow to the face of the bluffs. Hypotheses for how these materials were deposited are as follows: an ancestral Columbia River system entered from the northwest; the Salmon/Clearwater/Snake system entered from the southeast; and an ancestral Crab Creek/Palouse system entered from the northeast. Sand would have been deposited from all three systems, and that sand can affect how water flows. These hypotheses need to be tested to further define their existence and location.

- It is known that there are low permeable layers that impede downward movement of water and force lateral movement. It is also known that water moves vertically to layers at depth; piezometric readings show saturation in the clay layers below. Piezometric levels have changed after the source of water is removed. There has been an impact at depth, not just in the upper zone. The primary dip of these beds is 92 feet per mile (about 1^{o}) toward the river; so seeps at the bottom of the bluff could have originated at the surface about three miles away. Thus, there is some vertical movement of water, perhaps like down a ramp or stairsteps. This is known, in general, but not specifically for any location. There can be big differences in permeabilities over short distances that are not fully understood.

- In a saturated system, the incline of strata is less important than the hydraulic gradient. Dipping strata, however, can exert geologic controls on the movement of water.

- Is the groundwater system in equilibrium? Today the system seems static rather than dynamic. More than a decade ago, the U.S. Geological Survey (USGS) groundwater studies suggested that the system was close to being in equilibrium. Overall, since

[92]Facies are defined on the basis of specific physical properties. In sedimentary rocks these properties include color, bedding, composition, grain size, mineralogy, texture, fossils, and sedimentary structures.

the start of the Columbia Basin Project, the system has probably moved to 90% equilibrium, except for seasonal or local effects.

- The group did not discuss any strategies to get the water out of the Locke Island landslide area, such as installing horizontal dewatering pipes into the Locke Island landslide.[93] Future studies directed at landslides on the White Bluffs should be directed at collecting the information necessary to mitigate landslide movement and predict future landslide hazards/impacts.

Conclusions

- The interaction of the following four factors is important to groundwater movement in the White Bluffs: 1) impervious layers; 2) hydraulic gradients of aquifers; 3) discontinuities in layers; 4) and stratigraphic incline toward the river.

- Groundwater under saturated conditions moves vertically through the Ringold layers. When water contacts a low permeability layer, it moves laterally along the layer and sometimes to the face of the bluffs. Some water penetrates through these low permeability layers which indicates discontinuities in the impervious layers and multiple pathways for groundwater movement

Question 4b: How could one best track groundwater flow in and through the White Bluffs?

Key Points from the Discussion

- Currently groundwater movement is tracked via wells.[94] The problem is that the wells are as discontinuous as the groundwater – that is, there is not a systematic grid of wells providing data.
- Radioisotopes might be used to track groundwater movement.
- Chemical tracing methods are better at ruling out sources than pinpointing sources, especially in a system where there is so much mixing of water.
- There is an intriguing new technology (Aquatrack) that sets up an electrical current with electrodes at depths up to 1500 feet and that lets you map electromagnetic fields at the surface. It has not been tested in this area. Its scale of application would fit Locke Island, not the whole basin. It would need to be backed up by good geological information.
- Wells are drilled for different purposes; information from different types of wells may not be compatible and/or permit drawing conclusions. If landslides were the sole focus of data gathering, the monitoring would likely leave out information that is useful for other purposes. In any case, there needs to be better coordination.

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93 Reviewer's Comment: It is not clear that horizontal drains would work in fine-grained materials. The possibility of installing horizontal drains could be investigated.

94 Reviewer's Comment: The extent of tracking, except at Locke Island, is not clear.

- How well are well data coordinated? No one is looking at all of the well data; there has not been financial support for that.[95] The South Columbia Basin Irrigation District (SCBID) monitors the largest number of wells (shallow observational wells drilled by the USBR from Pasco to the Wahluke Branch Canal) on a consistent basis. Other than permitted facilities, these wells are the only ones being read consistently. The USGS has not monitored any wells in the past 10 years. When the USBR initiated the Locke Island study, only one or two of the eight wells in the area by the old White Bluffs lakes were useful for the Locke Island study. USBR drilled new wells for sampling and future water-level monitoring.
- The Columbia Basin Groundwater Management Area (GWMA) hopes to integrate well-data information in the future, but that part of the GWMA work has not started yet. GWMA will end up with generalized information that may or may not be useful for an individual landslide.
- Would there be value in consolidating well information? GWMA is doing this to the extent of its resources. If there is a suggestion to add a new parameter or seek resources to add wells, GWMA could consider that because GWMA is trying to accommodate the needs of agencies and local people. GWMA has done the basalt characterization work and is beginning to characterize sediments. The sediment work will take a year or more. Eventually there will be a geologic structure into which groundwater information can be added. Water will be investigated in the third phase. The GWMA work will not provide all the answers but it will accumulate information regionally.

Conclusions

- The level of study that has been done for the Locke Island landslide has not been done for the other landsides.
- Additional wells and a coordinated monitoring and data compilation effort are needed. It is not known how this will be supported and funded.[96]
- More wells would be useful in compiling groundwater data.
- Chemical and radioisotope tracer information could possibly be valuable on a site-specific basis.

Question 5: Do elevated groundwater levels contribute to landslides of the White Bluffs? If so, how?

Key Points from the Discussion

- Water is discharging at the White Bluffs; this did not occur before irrigation.
- If water levels in the Columbia Basin Project area have only been stable for the last 15 years, it is not clear if the maximum discharge has occurred yet or not. Some

[95] Reviewer's Comment: Determining where financial support would come from is an unresolved issue.

[96] Reviewer's Comment: A decision needs to be made concerning where this information should be consolidated.

seepage lines appear to be rising. In those parts of the White Bluffs, the crest may not have arrived yet. In sum, in parts of the White Bluffs, levels may be rising; in other parts levels may be stable; in other parts, levels may be dropping. The answer to this question is not known.

- Other influences come into play in the travel of groundwater. For example, the 1,250 miles of underground drains that the USBR installed lessens the amount of groundwater recharge. That drainage system intercepts a lot of potential groundwater recharge and keeps groundwater levels from rising any further.
- Are any areas getting dryer or wetter? More is known about the Locke Island landslide than about the other landslides along the White Bluffs. There is a general, if slight, decline above the Locke Island landslide. The former pond is totally dry and has been since 1998, but water still seeps out of the scarp of the Locke Island landslide. The Johnson Island seep line is moving north, which generally indicates that the groundwater level is still rising. Does the plume movement mean there is more water or is the water flattening out? The answer is not known. Each of these is an individual case.

Conclusions

- The answer to the question is yes, groundwater contributes to landslide activity, but it is not known how. To figure out how at each case requires an engineering analysis of slope angle, material strength, and pore pressures.
- No one generalization will work for all of the landslides because they are not the same. Each landslide is unique.

Question 6: What does monitoring show about trends in groundwater levels? Are they stable, rising, or falling?

Key Points from the Discussion

- In Smith Canyon, water levels are rising after years of decline. This change could be a result of the fact that SCBID drains several thousand acre-feet from the Potholes Canal into the Canyon.
- The USBR wells that SCBID monitors are mostly shallow; the deepest is 98 feet. Water levels in most of them are relatively stable. The big rise in the water table occurred in the 1950s when the Columbia Basin Project began to deliver water.

Conclusions

- Since the mid 1980s, groundwater levels are stable for a large percentage of this area. However, where there are changes in surface land use involving water (adding or removing ponds), levels are still in flux.

Question 7: What are the geologic controls for entry of groundwater and sources of groundwater that contribute to landslides?

Key Points from the Discussion

- The Ringold Formation contains layers of varying permeability. These layers control the flow of groundwater within the Ringold Formation. Groundwater migrates vertically through permeable layers down to the top of low permeable units and continues to flow along the upper contact of the low permeable units to the face of the White Bluffs. Researchers also know that there are windows or preferential pathways within the Ringold Formation that allow groundwater to reach deeper within the formation and thus deeper within the White Bluffs. The extent and location of these windows or preferential pathways are not well understood.

Conclusions

- Except for the White Bluffs Wasteway pond (above Locke Island) and possibly the WB 10 Pond area, there is no identified point source for the water at any of the landslide areas. More geologic investigation is needed for the other landslides.

Question 7a: At Locke Island?

Key Points from the Discussion

- A unique set of geologic conditions controls groundwater movement at the Locke Island landslide. The recent USBR study of this landslide identified three layers in the upper Ringold: a lean clay, a fat clay, and a differentially cemented sand layer near river elevation. At the White Bluffs above Locke Island, the top layer is missing and there is a channel filled with a multistory sequence of compact glaciofluvial and aeolian sand. This paleo-channel extends in a north-northeast trend at least three miles back from the bluff. The ponds created for wildlife in the late 1960s (now dry) were unwittingly located over this channel. The paleo-channel appears to have provided a pathway for the water from the ponds to infiltrate through the sands deeper into the Ringold clay layers. The channel funneled water down into the Ringold sediments above the slide and activated sliding.

- A hypothesis for this area is that an ancestral Crab Creek flowed across the northern part of the Pasco Basin and discharged into the Columbia River at the point of the Locke Island slide. If this interpretation is correct, then the ancestral Crab Creek stream bed would have potentially formed the paleo-channel. If this hypothesis is correct, it could mean that the channel extends farther to the east. Gravel deposits exposed at the south end of Radar Hill indicate an east-west trending side stream draining the Palouse Slope to the east and oriented toward the Locke Island area. The eastern-most hole drilled by the USBR did not encounter the channel.

- In the distant past (over three million years ago) the ancestral Columbia River system was periodically backed up behind blockages of the channel downstream of Wallula Gap and inundated the Pasco Basin. During that time, waters entering the Pasco Basin from an ancestral Columbia River system, the Salmon/Clearwater/Snake system, and an ancestral Crab Creek/Palouse system deposited sediments associated with three lake-filled systems. The sediments deposited in these lakes comprise the upper half of the White Bluffs. Studies to date have found evidence of only one river flowing into the basin during the lake fill period. There may be unidentified incoming or distributary channels that have been eroded into the Ringold sequence. Such channels could control the vertical infiltration and lateral migration of groundwater. The information on the channels could be critical to determining the processes and mechanisms for current landslides, preventing future landslides, and predicting landslide hazards. Currently, the geologic studies of the White Bluffs area have not been detailed enough to identify if or where these channels exist.

- Does this same pattern exist in the other landslide areas, or not? Detailed studies would gather the necessary information about each landslide to answer this question.
- Groundwater is still discharging from the face of the bluffs and the landslide even after the wasteway ponds have been emptied. It will take a lot longer to dissipate water from the Ringold sediments than it took to charge the Ringold units.

Conclusions

- A paleo-channel at the Locke Island landslide provided a conduit for rapid transport of groundwater, in a relatively short period of time -- 10-15 years. The water in the ponds above Locke Island had to travel only slightly more than one mile to reach the face of the White Bluffs. Details of how the water reached the lower part of the bluff are unknown.

Question 7b: At Savage Island?

Key Points from the Discussion

- The Savage Island landslide is apparently different from other landslides along the White Bluffs in that the Savage Island landslide does not have water seepage from the top of the scarp. The upper portion of the scarp appears relatively dry with groundwater emanating upward from somewhere within or beneath the landslide mass.
- Infiltration of surface water appears to be controlled by the surface geology which includes a surface aeolian sand cover in the form of sand dunes or sand sheets that overlies coarse-grained glaciofluvial sediments. The coarse nature of the surface material does not allow for significant moisture retention in the near surface for evapotranspiration and contributes to recharging the vadose zone. However, no detailed geologic studies have been done at Savage Island to determine geologic controls and little is known about this landslide.
- There are some flood channels at the top of that slide. It is unknown whether any of the paleo-channels are hydraulically connected to a pond, wasteway or other source of water. A detailed geologic study would identify these features.
- Is the water source on-farm application from the alfalfa field above the slide? If it were, one would expect to have seep lines in the landslide scarp and spreading at the cliff face. That is not happening. It is not clear how much water has infiltrated below the irrigated field and contributed to the landslide. Water exits the landslide at depth, at the bottom of an old paleo-channel. There is an alluvial-filled channel

there, somewhere, that could bring water from a considerable distance east of the landslide. The geologic mechanisms and processes that resulted in the Savage Island landslide may be associated with groundwater that percolated from irrigated fields or canals located on the high terrain behind the White Bluffs. Alternatively, the source of water could be the regional water table.

- The Savage Island landslide also has a prehistoric component. It is not known how groundwater has behaved within the landslide complex. Groundwater may have caused reactivation of the prehistoric component of the landslide or groundwater may have activated other geologic processes or mechanisms that are restricted to the recent component of the landslide.
- It is also possible that this area could be a point source for draining regional water, which could explain the presence of the old landsides.
- There appears to be an old remnant slump at the toe of Savage Island landslide, showing there is a prehistoric component. Is less water needed to reactivate an old landslide? Studies to date have not addressed this issue.
- It appears that the water level in a lake created between the toe of the landslide and a lower ridge composed of Ringold sediments is continuing to rise. Groundwater seeping out from the north end of the landslide discharges as surface runoff into the landslide-dammed lake. Continued accumulation of water in the lake may create additional structural instability of the Savage Island landslide. Groundwater seepage may be occurring near the south end of the landslide but does not discharge to the surface. Groundwater accumulating in that area could possibly create additional slope instability.
- The structural stability of the lower ridge that is situated in front of the toe of the Savage Island landslide is in question. The lower ridge could be a prehistoric landslide that may be structurally unstable and could fail with additional movement on the Savage Island landslide. The influx of groundwater associated with the Savage Island landslide may also be weakening the structural stability of the lower ridge.
- Water that is supplied to the surface through irrigation or by leakage in the irrigation canal system apparently has percolated into the subsurface and migrated downward past the first low permeable layers within the Ringold Formation. The low permeable layers are either discontinuous or contain higher permeability structures that allow groundwater deeper into the Ringold Formation and Savage Island landslide. The geologic controls at the Savage Island landslide include discontinuous low permeability layers that allow for the infiltration of groundwater. This is different from the geologic controls at Locke Island where the impervious layers preferentially carry groundwater out to the face of the White Bluffs.[97]

[97] Reviewer's Comment: Some of the water must percolate to deeper layers before reaching the bluff face at Locke Island as well.

Question 7c: At Homestead Island (also called the Ringold Landslide)?

Key Points from the Discussion

- The Ringold Wasteway extends to the edge of the bluff above the landslide. Because of the alignment with the wasteway, people have assumed that the problem is associated with water leakage from the wasteway. This hypothesis has not been confirmed through detailed studies.
- One potential explanation for the failure of the wasteway is the vibration from the large volume of water flowing in the wasteway. This hypothesis needs to be tested in any additional study of this landslide.
- Are the irrigation ponds above the bluffs, off the wasteway, a contributing factor? Is the wasteway the problem? No studies have been conducted to document this. The closest water source, other than irrigation, seems to be the ponds to the north and the wasteway above the canyon. There is a lot of area to the north and south of the wasteway that did not move.[98]
- One should not just assume that the ponds leak. When the USBR classified the prospective Columbia Basin Project land, the Bureau bored holes up to eight feet deep throughout the Project area; so data on the soil types exist. When the facilities were built, additional holes were drilled to evaluate the foundation conditions.[99]
- The large numbers of buried drains in the area should also be considered. They drain the upper eight feet. The influence of the drain system needs to be factored into the analysis.
- Other factors may be at play besides irrigation. When the DNR geologists characterized the 1996 landslide at Homestead Island, they attributed it to the combination of continued groundwater flows and heavy rain/snowfall before the landslide occurred. Seasonal issues have been identified as contributing to landslides in other locations. Weather conditions should be included as a factor to be considered in any additional studies of White Bluffs landslides.
- Water that is applied to the top of the Ringold Formation will infiltrate downward into the Ringold sediments by moving along discontinuities. If there are more sands/silts present in the sediments than clays/silts, there will be more percolation. Some of the grain size variation is likely attributed to depositional environments such as the distributary systems into the three lake-fill sediment sequences at the top of the White Bluffs. Geologic features that control preferential groundwater movement such as the distributary stream deposits have not been mapped in the Ringold sediments. Geologic mapping at sufficient detail to delineate these geologic features needs to be considered in new studies of landsliding on the White Bluffs.
- The source of water involved in the landsliding may be due to an elevated groundwater table or may be from a localized perched source of groundwater. There

[98] Reviewers Comment: Parsons and Rankin Canyons are south of the Homestead Island landslide and would not intercept groundwater moving towards the landslide area.

[99] Reviewer's comment: These data are available in the specifications.

currently is insufficient information to determine which of these alternatives is contributing to this landslide.

Conclusions

- Water exits all along the bluff, but with the information available, it is difficult to determine if the source of the water associated with the landslide is coming from ponds, the wasteway, the regional water table, or a combination of these sources.
- One can speculate on what causes landslides at the top, middle, and the bottom of the bluffs, but the geologic controls at Homestead Island are not really understood. Less information is known about the Homestead Island landslide area than about any other landslide area along the White Bluffs.

Question 7d: At Johnson Island?

Key Points from the Discussion

- The geologic mechanisms and controls that caused the Johnson Island landslide are not known.
- In the late 1960s and 1970s, some orchards, including the Haymaker orchard area, were developed by planting trees in holes that were created by dynamiting through the thick caliche cap at the top of the Ringold Formation. These holes may have created preferential pathways for irrigation water to move through the caliche out of the zone of evapotranspiration and downward into the Ringold sediments. The source of the water from the landslide may be coming from a rising regional water table. The Ringold Formation extends considerable distance to the east with a 1^{o} dip towards the river. The source area of the water may be several miles to the east. This interpretation is consistent with the rising water table in the north Pasco area. The 1993 Drost report[100] shows the water table rising significantly and regionally. That was also Bill Marratt's[101] conclusion. The source of the groundwater associated with this landslide may be related to an overall rise in the regional water table.
- Is the problem "leakage from ditches," as Mr. Haymaker has claimed? He has had test holes dug 20 feet deep and, in general, they have been pretty dry. So, it looks like it is deeper water than that coming from the irrigation ditches. *(Please see questions 20 and 21 below for discussion of irrigation canals.)*
- Almost all of the landslide activity has occurred in the units above the basal gravel of the Ringold Formation. That gravel or conglomerate buttresses the hillside and has not been involved in any landslides observed so far.

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[100] Brian W. Drost, James C. Ebbert, James C., and Stephen E. Cox, Long-Term Effects of Irrigation with Imported Water on Water Levels and Water Quality. US Geological Survey (Water-Resources Investigation Report 93-4060, Tacoma, WA 1993, 19 pp.

[101] W.J. Marratt, Study of Landslides along the Columbia River in the Block 15 Area of Franklin County, WA, Franklin Conservation District, 1988, 26 pages with four pages of economic analysis.

Question 7e: At WB 10 Pond/Wiehl Ranch?

Key Points from the Discussion

- This landslide area is nearly as large as the Locke Island landslide area. The toe of the landslide has moved into the river at the south end of the Wiehl Ranch bench. This area was very active in the late 1980s. A small pond above the head of the landslide was drained in 1991. While landsliding may have slowed due to the draining of this pond, some activity continues.
- No detailed geohydrologic study has been done to determine the effects of the draining of the pond on landslide movement at the WB 10 Pond/Wiehl Ranch landslide.
- The geology has not been studied in detail at this site. Consequently, the geologic controls (e.g., paleo-channel deposits like those observed at the Locke Island landslide) that influence the movement of groundwater at this site are not known.
- Water levels from wells located near the old pond area have risen 70-80 feet in the last 20 years. There is concern that there may be conditions of perched water or paleo-channels similar to the Locke Island area. In 1993 there was a failure along the south or left side of the WB 10 Wasteway where it passes through a small canyon before discharging into the Columbia River. This failure affected up to a half million cubic yards of material. SCBID conducted emergency repairs on the wasteway and surrounding bluffs. Two years later USBR replaced the damaged section of the wasteway with an underground pipe that transported the water down the bluffs to the Columbia River. Since then the slope along WB 10 Wasteway has been generally stable, with most of the recent movement occurring further south.
- The WB 10 wasteway is used to support the distribution of wastewater from two small wasteways during the irrigation season.
- The WB 10 Pond is about 300 acres in size. It serves as a collection point for groundwater, in general, from various sources: the drainage system; emergent groundwater; water from the northeast, from the north flowing south, and from the northwest. The pond is used primarily for wildlife habitat, not to support agriculture.
- The WB 10 Pond collects a sufficiently large volume of water that it could not be drained cost-effectively through rerouting the water via a piping system. An alternative would be to decrease the size of the pond by building a canal to move water to the river and reduce the groundwater recharge in the pond area.
- The source of the water being discharged to the pond may come from far away areas, including Radar Hill and possibly other sources. The water is not coming from a point source, but rather from multiple sources at great distances. The pond collection area is a regional issue that needs to be addressed for the southern portion of the Columbia Basin Project.
- A difference between the WB 10 Pond landslide and the Locke Island landslide is that the impact to the river is minimal at the WB10 Pond area under normal flows. Most of the landslide debris ends up on the Wiehl Ranch bench, which is constructed

of glaciofluvial gravels and covered with colluvial and prehistoric landslide debris from the White Bluffs. A small amount of the recent landslide debris enters the river at the south end of the Wiehl Ranch bench into a low energy area of the Columbia River channel. Unlike the Locke Island landslide, this area is not in the midst of a salmon redd area.

Conclusions

- The geologic controls surrounding the WB 10 Pond/Wiehl Ranch landslide have not been studied in detail. The impact that ponds are having in this area is not fully understood. It is clear that the groundwater is rising in this area but the impacts from the rising groundwater are uncertain. The workshop participants did not have a basis for recommending draining the wildlife pond and believe that a better understanding of the geohydrologic conditions at the WB 10 Pond/Wiehl Ranch landslide area are needed before recommendations can be made
- If the wildlife pond were to be drained, the water that comes from multiple source areas would need to be significantly reduced in flow rate to the pond or discharged elsewhere before piping wastewater from the pond area to the river would make sense.
- The WB 10 Pond area merits study because the water levels in the wells between the pond and the bluffs have risen from 60-80 feet since the late 1970s.
- The workshop participants recommended not to drain the pond until the connection between the pond, groundwater, and landslides are better understood. An engineering evaluation should be conducted of this area.

Question 7f: At a new landslide area at River Mile 360? (A mile north of Savage Island)

Key Points from the Discussion

- The workshop participants tentatively named this new landslide area the "River Mile 360" landslide area. It is located about one mile north of Savage Island, three miles north of the Hanford BPA-line, and opposite Parking Lot 6 at River Mile 360. These new landslides are geologically disconnected from the Savage Island landslide complex.
- This area of landslide activity has been developing since about 1990. The amount of water discharging from the slide has increased. The saturation zone has extended laterally and goes down to an aquiclude before discharging out from the face of the White Bluffs. Landslides from the bluffs move as debris flows into three erosional gullies. The largest of the landslides is a significant debris flow that has moved down the erosional gully and out onto a colluvial apron in front of the bluffs.
- The water discharged from the bluffs originates from relatively impervious Ringold Formation lake-bed clay deposits. It is not clear which specific unit or units form the low permeability beds on which the groundwater is moving. It is uncertain if the source of the water is directly from irrigation water applied to the orchard at the top

of the bluffs or from groundwater that is moving south and southwest towards the bluff face or from a combination of the two. A detailed geohydrologic study is needed to determine the source of the water in this landslide.

- There is a significant wetting front that is exposed along the bluff face as well as seepage discharging from the bluffs. The amount of groundwater present in the wetting front and seepage areas suggests the possibility that a large slump could be generated along this portion of the bluffs. The potential slump area would be located at a considerable distance from the river. The debris flow does not appear to be causing significant environmental damage.

Conclusions

- Gullies and canyons can serve as geomorphic controls, intercepting and draining water that otherwise would seep out from the bluff face. Considering the location of major drainage gullies on either side of this landslide, it is clear that the source of water has to come from direct application of irrigation water at the top of the bluff or from groundwater moving south to southwest towards the bluff face.
- This is a new landslide area and provides an opportunity to systematically evaluate geohydrologic mechanisms and processes that are causing the initiation and continued activation of landslides along the bluffs. This landslide should be observed or monitored based on a well-defined plan.

Question 8: Is the water problem at Locke Island a case of perched water from ponds created in the late 1960s (now dry) or elevated groundwater levels that have saturated the soil column?

Key Points from the Discussion

- This is a deep-seated failure. The mechanism causing the landslide is not fully understood. At Locke Island there is 350 feet of Ringold Formation. The paleo-channel exists in the upper one-fourth of the bluff.
- Is the paleo-channel deep enough to let water reach into a deeper lake deposit in the Ringold? Could there be another pathway for seepage to infiltrate deeper? Potential pathways are unknown at this time.
- The USBR drill holes located in the upland behind the bluff were sampled continuously during drilling and the soils were competent and solid. When USBR looked at the soil samples 2-3 years later, they were dried out and cracked. Perhaps along the face of the bluff and some distance into the bluff the materials are drying and cracking. Then, if water reaches the cracks, it follows them into the materials behind the bluff face and causes slope failure. Thus, drying cracks in the Ringold Formation near the bluff face may have provided pathways for the water to penetrate to greater depths.
- How continuous are the clay layers there? These layers are pervasive throughout the upper Ringold.

- As a result of its recent study, USBR concluded that perched water entered the Locke Island landslide area by seepage from the ponds located above the bluff. This water migrated through pervious sands to the face of the bluff.

Conclusions

- The workshop participants believe the source of the problem at Locke Island is both perched water from the ponds and deep groundwater, but the source of the deep groundwater has not been studied.

Question 9: What effect, if any, does irrigation have on groundwater movement at the Locke Island landslide and on the WB 10 Pond/Wiehl Ranch landslide?

Key Points from the Discussion

- The recent USBR work in the Locke Island landslide area did not identify direct irrigation as having any impact on the Locke Island slide; USBR thinks that current movement is due to residual water from the wildlife pond. However, it is not clear that the regional water table is not part of the problem at the Locke Island landslide. Even though water levels in wells have dropped some, a question remains as to what is maintaining the water levels there.[102]
- Drilling new wells farther back and some geophysics work would help to clarify how far back the paleo-channel goes. The USBR measured it three miles back. It could be part of an ancestral creek system. It is unknown whether irrigation to the east might influence seepage at the Locke Island landslide.

Conclusions

- In the Locke Island landslide area, it is not known if the water source is local or regional. It is clear that the pond water at the surface is gone and that it is taking a long time for the groundwater to dissipate from the Ringold units. It is not known if irrigation to the northeast is contributing to the seeps near Locke Island. Both are possibilities.

Question 10: What are the similarities and differences in the causes of landslides at Locke Island, Savage Island, Homestead Island, Johnson Island and west of the WB 10 Pond/Wiehl Ranch?

Conclusions

- The similarities are that water is being added to the system and, in every case, water is a major contributing factor to slope instability.
- The extent of paleo-channel deposits in the upper bluff at Locke Island is significantly different from everywhere else, except, possibly, Savage Island. Elsewhere, paleo-channel deposits are not as obvious or distinct as they are at Locke Island. The specifics are still unknown.

Question 11: Are there identified areas in the White Bluffs that are more susceptible to landslides than others?

<u>**Key Points from the Discussion**</u>

- The south end of Ringold Coulee has conglomerate outcrops at the base of the bluffs that serve as a buttress against sliding.
- Any place where water is being added that weakens the strength of soils could be susceptible to landslides. However, the details on groundwater flow and geologic controls within the Ringold Formation and landslide debris are not well understood. For example, a prehistoric landslide may truncate permeable, water-bearing units causing water to back up and increase saturation, resulting in additional landslide activity. Additional study is needed to understand geohydrologic controls on water movement in Ringold sediments with low strength when moisture/water content is increased.
- If there is need to develop wetland areas, the geologic conditions should be assessed before establishing a wetland area. For example, the Saddle Mountain Lake area or the coulees are ideal places from a geologic perspective because they are not going to slide.

<u>**Conclusions**</u>

- The internal geohydrologic characteristics of the Ringold Formation needed to understand the potential for movement and landsliding are poorly understood. Therefore, landslide susceptibility all along the bluffs cannot be predicted. It is clear that application of water on the Ringold Formation and the existence of sand-filled paleo-channels at the top of the bluff (such as at Locke Island or Savage Island) increase the susceptibility to sliding. Areas at the base of the exposed Ringold Formation that contain thick sequences of cemented gravel are not as susceptible to landslides as finer-grained sediments found in the upper part of the Ringold Formation.

Question 12: Are there areas between Locke Island and Johnson Island that have not experienced landslides that can be expected to experience them in the future? If so, which ones and why? What about south of Johnson Island?

<u>**Key Points from the Discussion**</u>

- Landslide activity may continue to move north of the current Johnson Island landslide complex as the wetting front and seep lines continue to move north along the face of the bluffs.
- Landslide activity is possible in some of the large, erosional canyons in the Ringold Formation. Two possible areas are Rankin Canyon and the canyon between the

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102 Reviewer's Comment: It will take much longer for the Ringold units to drain than it took for them to be charged with surface water.

Haymaker and Sullivan properties where water has been running down the canyon for the last six to seven years.

- The River Mile 360 landslide area is a new, developing area that should be studied. Aerial and ground photos are available showing development of seepage and landslide activity. Physical evidence of slumping and debris flows can be observed in the field.
- The Locke Island landslide still has seepage emerging from the landslide headscarp; thus, landslide activity is expected to continue but at a reduced rate compared to the last several years.[103]
- There is potential for prehistoric landslides along the White Bluffs to be reactivated due to increased water seepage from the bluffs. The geohydrologic processes and mechanisms that originally formed these landslides or could reactivate these landslides are poorly understood.
- A moratorium on new irrigated lands was established in 1993. The SCBID does not plan to irrigate new land areas.
- At Taylor Flats there is a potential for future landslide activity. The bench at Taylor Flats is composed of a core of Ringold conglomerate that is very unlikely to slump. However, the steep slope of the White Bluffs behind the bench is composed of clay, silt, and sand that have the potential to fail if the moisture content increases sufficiently to reduce the strength of these sediments. There is evidence of seepage of water from this slope as well as increased vegetation that indicates increased moisture content. This area of the White Bluffs should be subject to study.

Conclusions

- Where water is added to areas along the White Bluffs that have experienced landslide activity, continued landslide activity can be expected.
- Landslides are unlikely to occur upstream from the Horn of the Columbia River where the slope and elevation of the bluffs are lower.
- From the north end of Locke Island to the Horn of the Columbia River, landslides in the form of earthflows and slump blocks can continue to occur because of undercutting of the White Bluffs by the river.
- Landslides are unlikely to occur south of the Johnson Island area. In this area the topographic expressions of the White Bluffs die out and the area forms a large glaciofluvial flood bar that has sufficient permeability for groundwater to infiltrate to the water table without extensive perching and formation of seepage areas along the upper parts of the bar.

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[103] Reviewer's Comment: The occurrence of water from the slide face does not necessarily foretell additional landsliding. Since the water is discharging and not building up inside the landslide mass and increasing pore pressures, the draining water could actually be a good thing.

Question 13: What sets of factors contribute to the landslides of the White Bluffs?

Key Points from the Discussion

- The geologic contribution -- the physical properties of Ringold Formation -- is clearly important: the transmissive character of silt and sand layers and the lack of permeability in the clays controls water distribution. These layers get wet, lose shear strength, and fail at the bluff face. Also important is the fact that the layers slope slightly toward the river and perch water that can then flow toward the bluffs.
- Groundwater changes caused by irrigation (and everything that entails) have contributed to the landslides because adding water to weak materials causes them to fail.
- Pond seepage has contributed at the Locke Island landslide and draining the pond closest to the river has helped to slow down the impacts (at the Locke Island landslide and the WB 10 Pond areas).
- With respect to canals, people have a misconception that if the linings of the irrigation canals could be made to be impermeable, the problem would go away. Every irrigation canal has multiple functions. They deliver water; but, because they are often in cut-and-fill sections, with irrigation going on above and below the canals, they also collect water and relieve pore pressures.
- Irrigation canals leak, even those that are lined. It is a question of how much. SCBID is working on the Wahluke Branch Canal right now to put seepage wells in the sides of the canal so that when the District dewaters, the water goes back into the canal without damaging the lining. Canal linings crack with age. SCBID uses hundreds and hundreds of gallons of sealant each spring to seal the cracks, but linings continue to crack over time.
- Erosion and undercutting are important from the Horn of the Columbia River downstream to above Locke Island.[104] Along much of the remaining shoreline of the Columbia River to the south of Locke Island, the channel margin is bounded by a set of paired terrace steps that indicate channel stability with little lateral channel migration occurring over the last thousand years.
- In areas where the toe of the landslide has migrated out into the river channel, the river may erode away the toe of the landslide, resulting in continued movement of the landslide and bluff instability.

Conclusions

- Three different factors contribute to the landslides: the physical properties of the Ringold Formation, the introduction of water and the rise in groundwater, and the undercutting by the river near Locke Island.

[104] Reviewer's comment**:** Significant undercutting by the river in the Locke Island area has not been observed recently.

- Other factors such as bank-swallow nests and boat wakes have not contributed to the landslides along the White Bluffs.

Question 14: What impact have fluctuations (annual and daily) had on erosion and sedimentation in the river? Have erosion and sedimentation rates changed with time?

Key Points from the Discussion

- River erosion causes undercutting of the outer bank near the Horn of the Columbia River and over-steepening of the White Bluffs, leading to earthfalls from the bluff face.
- Another possible mechanism affecting erosion is the impact of rapid drawdown at Locke Island. Rapid drawdown occurs when the water level drops suddenly. When the water level is high, water flows into the toe of the landslide. The water adds extra weight and increases pore pressure. When the water level drops rapidly, the extra weight and elevated pore pressure in the slide mass contributes to slump. The severity of the slumping depends on how quickly the materials drain and the difference between high and low water levels.
- Landslides that extend out into the river channel experience erosion along the toe and the resulting transport of sediments downriver modifies the river channel. At Locke Island, the landslide extended about 150 yards into the channel between the White Bluffs and Locke Island and resulted in a narrowing of the channelway. The restriction caused an increase in flow rates through the channel and the development of channel deposits (e.g., a transverse bar and riffle), just off the east bank of Locke Island. Also, a sand bar developed near the toe of the landslide at the downstream end.
- Similar sedimentation events are occurring in the Columbia River at the downstream end of the WB 10 Pond/Wiehl Ranch landslide area.
- Several other bar types have developed downstream of the landslide restriction of the Locke Island channel. Plumes of eroded material are visibly being transported downstream. These plumes are mainly related to increased flow through the restricted channel and are not due to fluctuations in river level. So, erosion and sedimentation rates have changed since 1996 because the landslide extends out into the river channel.[105]
- Another kind of sedimentation is occurring as a result of landslides, but outside of the river channel. Large crestal sand dunes are developing at the top of the White Bluffs that stretch the length of many of the recent landslide areas. The largest of these crestal sand dunes are present above the Locke Island landslide. Prevailing westerly winds have picked up fine grain sediments from the landslide debris, transported the sediments up the bluff face, and deposited the sediments on the lee side of the bluff crest. These dunes are active and continue to increase in height and extend to the east

[105] Reviewer's comment: It is important to note that erosion and sedimentation also occur in areas that do not have landslides.

from the top of the bluffs. It is not known if the additional load from these crestal sand dunes will result in additional instability along the head scarp of the landslides. This may be unlikely as long as the landslide is serving as a buttress. Then the bluff will likely remain stable.

- The crestal dunes developing above the WB 10 Pond/Wiehl Ranch area are smaller in size than the ones at Locke Island. The presence of these crestal dunes may suggest the existence of a paleo-channel near the top of the bluffs above Wiehl Ranch[106] because that is where the fines at Locke Island come from.[107]

Conclusions

- River erosion does not trigger landslides along this stretch of the Columbia River, except for minor earth falls and slumps near the Horn of the Columbia River where the river undercuts the White Bluffs.
- River erosion adds to the instability of active landslide areas by removing the toe, which tends to result in increased movement of the landslide.

Question 15: Are river-level fluctuations from power generation causing a problem?

Key Points from the Discussion

- The erosion in the Locke Island landslide area is not caused by river-level fluctuations. There has been relatively little erosion at Locke Island since the end of the high flows.

Conclusions

- Erosion by the Columbia River probably does not trigger landslides along the White Bluffs except for the minor earthfalls and slump blocks at the Horn of the Columbia River.

Question 16: Are there potential safety concerns associated with the landslides?

Conclusions

- Based on personal experience, workshop participants noted that hiking on or standing on the edge of a landslide is hazardous because the land is unstable. Earthfalls into the river can cause significant wakes that make boats unstable. There have been property losses over time, including agricultural fields that slid, farm equipment that was damaged, and county roads that have been destroyed.

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[106] Reviewer's comment: Is there a correlation between paleo-channels and crestal dunes?

[107] Reviewer's comment: There are numerous crestal dunes along the top of the White Bluffs starting at the Horn of the Columbia River and continuing all the way to at least Ringold Coulee. Most of these dunes are older dunes that are currently stabilized by vegetation. The active crestal dunes are located on the lee side of the top of the bluffs above active landslides. The landslide debris provides the source of the sand for many of these dunes and do not necessarily require the existence of a paleo-channel filled with fluvial or glaciofluvial sands.

Question 17: Can areas where landslides have occurred be prioritized in terms of risk?

Key Points from the Discussion

- If money were no object, detailed studies, such as the one completed for the Locke Island landslide, should be conducted at the other landslide areas: Homestead, Johnson, WB 10 Pond area, River Mile 360.
- The stratigraphy along the White Bluffs, primarily in the Ringold Formation, needs to be studies in sufficient detail to understand groundwater flow paths from the top of the bluffs to near the surface of the basalt. This includes determining the existence and location of paleo-channels and distribution, if they exist. Currently, few published maps and reports are available on the basic geology of the White Bluffs and Ringold Formation in the area being addressed in this workshop. If site-specific studies are undertaken, these studies should address and evaluate the presence of large-scale subsurface channels. Studies should not be restricted to such small areas that important geologic and hydrologic features that are important to understanding landslides are missed.
- Someone needs to identify the monitoring being done by different entities – USBR, Battelle, others. Is there a program to monitor the landslides? If so, is it adequate or not?
- The extent of the current USBR commitment is to continue to monitor movement of pins USBR placed at the Locke Island landslide area and to monitor water levels in the wells it drilled for the Locke Island study.
- USBR did groundwater monitoring until funding ran out in 1992. When SCBID learned in 1995 that this was no longer being done, it determined that the District needed the information and decided to continue to read the shallow USBR observational wells. These data help trend general drainage problems within the District. SCBID does not read deep wells.
- GWMA-sponsored work will develop regional stratigraphy that will be useful in showing where water can enter into the subsurface, but it will not be in sufficient detail to address many of the unknowns related to the mechanisms controlling landslides along the White Bluffs. The draft report on the geology of the area includes maps that portray the distribution of flood deposits and the overall distribution of Ringold, but the report does not show any subdivisions. Sediment studies (in the next phase) will break up the flood deposits and the Ringold into finer subdivisions. If old USBR well data are available, the study would like to include coarse/fine distributions. That could begin to delineate groundwater pathways. GWMA covers the depositional basins in Grant/Franklin/Adams counties. The GWMA boundary is the county lines, so, it includes the periphery around the Hanford Reach National Monument, but the data density is highly variable.

Conclusions

- There is much that scientists, engineers, and others do not understand about the landslides along the White Bluffs. After reading the reports over the years, some people have assumed that enough information is known about landslides to implement remedial action. The workshop participants concluded that more work needs to be done to understand the controls, causes, and conditions of the landslides. This is not a simple problem and there are no simple solutions.

Question 18: What contribution, if any, do agricultural practices make to the landslides through groundwater recharge?

Key Points from the Discussion

- It is necessary to distinguish between efficiency of delivery, on the one hand, and efficiency of water use to grow crops and keep the water in the root zone and not have it become recharge/leachate, on the other. According to Bob Stephens, a soil scientist, if there were no leaching, salts would build up and ruin farmland. There will always be some water passing through to keep the soil moist enough to grow crops. A goal is to have no more than 12-15% leachate. Switching to Irrigated Water Management (IWM) should allow agriculture to come as close as possible to that 12% leaching rate goal.
- USGS groundwater studies published a decade ago provide the only quantitative answers available for the White Bluffs. Historically, water use has declined. Rill irrigation that used four acre feet/acre in much of the Project area was never common in the SCBID service area because of the local topography. In SCBID's service area 95% use sprinkler irrigation which uses 2 – 2 1/2 acre feet of water/acre. There has been a dramatic change in technology over the 40-year period of the Project as a whole. Efficiency of water use has increased, which means that water passing through the root zone and into the aquifer has decreased.
- SCBID has documented reports (1994) showing on-farm use of water going down. (More recent data should be available in a couple of months.) The number of ponds has decreased dramatically. There are a lot of small diversions that turn water back into the system. The District is seeing increased efficiencies and a reduced amount of on-farm application.
- If there has been 10% less application of water on farms and less water from canal seeps, one would expect to see a corresponding drop in water levels in USBR's shallow observational wells. That has not happened. There could be a lag time in seeing changes in wells. Drain systems skim off the top of the groundwater; those systems would be one of the first places a change would be seen.

Conclusions

- In a 1986 study, water applied on-farm accounted for 40% of the recharge at the regional level. The amount of water applied has gone down and there is less recharge. GWMA estimates recharge at 15-20% at present on those farms that are using the new irrigation techniques.

Question 19: Are lined facilities (e.g., the Wahluke Branch Canal) monitored to see if water seeps from them to the ground below? If so, what are the results? Are unlined facilities monitored to see if water seeps from them to the ground below? If so, what are the results?

Key Points from the Discussion

- Not a lot of monitoring is done on the Wahluke Branch Canal. For the Locke Island study, the USBR drilled three new wells upgradient from the White Bluffs Wasteway pond location. One was located between it and the Wahluke Branch Canal to monitor potential seepage from the Wahluke Branch Canal. This well has been dry since it was drilled, although data from one well may be too limited to give a clear picture. The other two wells were located east of the pond location and near the west extent of the pond.
- The canal is 50 miles long and goes through many soil types and linings. SCBID does a lot of maintenance work on it. In general, it operates fairly efficiently. There are not significant problems of water loss from seepage; more is lost from the wind and evaporation than from seepage.
- SCBID conducts seepage tests to evaluate canal performance and efficiency before deciding on maintenance and rehabilitation activities. The District has 800 miles of canals and laterals; drains and wasteways are not included in this number. The District takes periodic readings but it does not do systematic, regular monitoring. District activities have more impacts that are farm-related, such as seepage onto a farm creating wet areas, and the District has to line or pipe the individual lateral to avoid damage to agricultural lands.
- Canals are lined and unlined for a reason. It depends on the type of material the canals pass through. Potholes Canal from the Ringold check area upstream to Road 170 is not lined because it goes through clay and does not need to be. There are not adequate data to evaluate the subsurface hydrological profile District-wide.
- Ditches that leak are obvious. If any irrigation district were losing 10% of its diversions, the district would take a look at it. SCBID is not seeing that in any of these locations. The District has a multitude of pumping plants; almost everything that is north and west of the Potholes canal is pumped up there. So the District is really aware of what is going on out there.
- In addition to SCBID's operations, there is also the issue of on-farm delivery systems, including the irrigation ponds, some of which are just holes in the ground. If they are leaking too much, something has to be done about it.
- Until 1991-1992, SCBID had low-cost excess water rates. Then, in 1992, after the Washington State Water Resources Association did a rate study, SCBID's Board of Directors instituted tiered conservation pricing to reduce water usage. Above the base quantity, people pay extra for more water – up to twice as much. As a result, people began to look at the cost of excess water, including for ponds, and to look for efficiencies. There have been similar increases in efficiencies of on-farm practices

since the early 1990s. At that time, 25% of the irrigation water applied on-farm went into groundwater; things have changed since then.

- During the USGS groundwater study, USGS staff concluded that pragmatic operational perspectives determined monitoring. The SCBID would monitor if there were a problem in a particular area but it would not monitor the whole system. Operational issues also determined what got lined. For example, if it seemed that a canal leaked more than one-half vertical foot per day, then the District lined it. Many lose a lot less.
- Since the USGS report issued more than a decade ago, SCBID has lined or piped about 27 miles of canals or laterals.
- Canal seepage is not the only source of water into the area. Other sources are on-farm application and precipitation. In the 1980s the USGS study identified that canal seepage contributed 60% of the recharge; on-farm applications contributed 40%. As a result of on-farm technologies in use, these percentages of recharge will change.
- GWMA's region-wide objective is to improve efficiency of on-farm applications through Irrigation Water Management. By 2001 GWMA estimates 300,000 acres were using Irrigation Water Management in a scientific way. The goal of GWMA is to have 400,000 acres reach that level of efficiency. National Resource Conservation Service (NRCS) funds are helping toward a goal of getting more acres to use this technology to increase on-farm efficiency for leachability. GWMA's expectation is that high land-use efficiencies will have an impact on recharge.
- However, if all leakage from the irrigation delivery facilities were stopped and recharge came only from on-farm application, water quality problems would shoot up because recharge would be coming only from the fields. Lining all canals would cause water-quality efforts to suffer.

Question 20: Why are some canals lined and others are not and what does being lined or unlined mean for groundwater recharge?

<u>Key Points from the Discussion</u>

- From an operational perspective, the District lines the canals that cause problems and does not line canals that do not need it. Canals are lined in permeable sections. Where they go through soils with very low permeability rates, they are not lined. Lining all the canals is not necessary nor is it *the* answer – that is a misconception. A lined canal is not an indication of water saved; it probably means it is a canal that leaks. Unlined canals remain unlined because they do not need to be lined. That is a more important fact than the number of miles of lined canals.
- The real question is not whether canals are lined or unlined; it is how much seepage gets to the groundwater. SCBID irrigates 230,000 acres, 180,000 of which are in Franklin County. SCBID has a conservation program. The District just had a consultant conduct a two-year study to develop a conservation plan (completed in 2002. It addresses efficiencies and prioritizes projects. The District took samples,

used USGS data, and developed its own data. SCBID operates within industry standards. SCBID places high priorities on conservation projects such as pipelines and linings in specific areas. The plan depends on annual priorities. In general, the District tries to do about four miles of pipeline a year.

Question 21: What differences are new irrigation techniques making in the quantities of water used for irrigation and in quantities of water that become recharge to groundwater? How widespread is the use of the new techniques?

Key Points from the Discussion

- See question 7 above for a discussion of on-farm efficiencies.
- Irrigation Water Management has been in use for the last 10 years on about 20% of acreage. In Franklin County that amounts to about 40,000 of 240,000 acres. GWMA expects the number to rise to 90,000 to 100,000 acres.

Question 22: Does water from the Snake River impact the groundwater in the Pasco Basin?

Conclusions

No.

Question 23: What has been the impact of the White Bluffs landslides on agriculture?

Conclusions

- There has been some impact on local growers, but from a regional standpoint, the impact of the landslides has been minor.

Question 24: What is the effect of rainfall in the White Bluffs area on groundwater hydrology?

Conclusions

- Precipitation that infiltrates into the soils above the White Bluffs is sufficiently low that precipitation, by itself, is unlikely to affect landslides along the White Bluffs.

Workshop Recommendations

Combined recommendations from these two workshops offered advice on future actions, identified additional studies/information needed for informed decision-making and requested a coordinated effort to collect and share information. They are presented below in that order.

1. Do not try to mitigate landslide activity until the causes of the landslides have been determined and mitigation measures have been evaluated.

2. Conduct a systematic inventory of the entire White Bluffs to lay out what is known about each landslide area.
   - Investigate and characterize the following categories:
     - Prehistoric landslides
     - Active landslides
     - Potential landslides
   - Address detailed, specific questions about causes and do not make assumptions as to the immediate cause(s) of landslides. A study should address if:
     - The problem is a seep line 100 feet below the bluff or 200 feet below the bluff;
     - It is a single or multiple seep system;
     - The system is dry or saturated.
   - Identify data and information gaps for each area.
   - Create a matrix that identifies the types of landslides; the causes /mechanisms of the landslides -- all the conditions at each landslide area. This means that each landslide area will have to be described adequately to perform a causal analysis. Key questions in this analysis include the following: Are groundwater levels going up or down? Is there continued movement of the landslides? Have any corrective actions been taken? If so, what were the results?
   - Identify potential impacts: erosion to farmland; increased sedimentation in the Columbia River; impacts to cultural resources; low/no impacts, etc.
   - Once the geologic and hydrologic controls of the system are well defined, alternative actions to mitigate landslides can be determined and a preferred alternative implemented.
   - Assign priority areas of study based on the results.

3. Conduct an engineering evaluation at the WB 10 Pond/Wiehl Ranch landslide area. This would determine the impact of the water on the slopes – today and in the future. What would happen if nothing were done?

4. Initiate a more systematic, long-term monitoring network.
   - To make scientific determinations on groundwater, an intense well system is needed so it can be monitored. Hydrographs for the wells would help to define impacts from applied water, storm events, etc., year to year and season to season.
   - Consolidate data from current and past groundwater monitoring sources: USGS, SCBID, USBR.
   - Include SCBID's recording device data; check winter data when groundwater is the primary source, rather than irrigation water, for hints about groundwater levels.

5. Establish an ongoing dialogue about the White Bluffs landslides. This workshop should be used as a basis for establishing a continuing dialogue on landslides along the White

Bluffs among interested parties.[108] Organizations should develop cooperative arrangements to deal with the natural system holistically, better utilize their resources, and give the taxpayers a better bang for their buck. It should lead to more opportunities to share information about ongoing programs, field activities, and data and data interpretations.

6. Identify a single entity to compile information on activities that address landsliding along the White Bluffs. This would permit developing a comprehensive understanding of what is being done by different agencies.
   - Identify who has historic aerial photos of the landslide areas.[109]
   - Continue taking regular aerial photos.
   - Identify sources of groundwater monitoring data and consolidate the data on groundwater as it relates to landslides in one central place so researchers can look at implications and understand continued impacts.

7. Coordinate efforts to avoid duplication.
   - Additional studying, monitoring, and collaboration of efforts are needed to understand what is happening and to develop a consistent long-term view.

[108] If there are to be future discussions, Shannon McDaniel indicated that SCBID has participated in discussions on other issues of interest to the District after signing Memoranda of Agreement. He indicated that SCBID would likely be interested in participating in discussions about the White Bluffs landslides, perhaps through a Memorandum of Understanding.

[109] USBR took aerials annually until funding ended in the mid 1990s. SCBID flew the river in 1996 and 2002.

Summary of Workshop Discussions on Impacts to Fish and Spawning Habitat

Participants

Name	Affiliation
Don Anglin	Fish Biologist, U.S. Fish and Wildlife Service, Vancouver, WA
Jeff Fryer	Fish Biologist, Columbia River Intertribal Fish Commission (CRITFC), Portland, OR
David Geist	Fish Biologist, Pacific Northwest National Laboratory (PNNL), Richland, WA
Paul Hoffarth	Fish Biologist, Washington Department of Fish and Wildlife, Yakima, WA
Ken Tiffan	Fish Biologist, U.S. Geological Survey (USG), Cook, WA

Questions Discussed

1. (a) What is known about the impact of sediment from the White Bluffs landslides on the salmon spawning beds in the Hanford Reach?
   (b) Is sediment silting up prime spawning habitat for fall chinook or other species?
   (c) Are the number of redds being reduced or relocated?
   (d) Are there negative impacts to spawning areas further downstream?
2. How does the current sedimentation rate to the Hanford Reach compare with the "natural" or historic rate of sedimentation?
3. Where do the sediments that are being deposited over the redds in the Locke Island area come from? From the White Bluffs or from further upstream?
4. Does the scouring effect of the higher river flows between Locke Island and the landslide cancel out the increased sediment load to the Columbia River from the landslide debris that reaches the river? What happens further downstream?
5. What impact, if any, has the increased sedimentation to the Columbia River had on spawning success? How can this be assessed?
6. What is known about possible impacts of sedimentation on the aquatic plant and insect communities along the White Bluffs?
7. Is there an impact of sediment on the physical structure or template of the Columbia River that would cause a change in ecology?
8. What impact have fluctuations (annual and daily) had on erosion and sedimentation in the river?

Observation about the Composition of the Workshop

The specialists on fish at the workshop said that it was difficult to assess impacts to the fish resource without having knowledge of the processes of the landslides themselves. They regretted that no geologist or hydrogeologist was part of the group to answer questions and participate in the discussions. In particular they had questions that could not be addressed about:

- whether the landslides would continue to progress northward;
- the role of unlined canals in contributing to recharge;
- trends in groundwater recharge and the prognosis for continued landslides;
- impacts of erosion on bank stability, especially at Locke Island; and
- what is expected in the next few years.

They recommended that future discussions about impacts to the Columbia River and fish should include specialists familiar with the geomorphology and hydrogeology of the river.

Discussion Summary

Question 1a: What is known about the impact of sediment from the White Bluffs landslides on the salmon spawning beds in the Hanford Reach?

Key Points from the Discussion

- David Geist brought two sets of maps showing fall chinook salmon spawning or redd locations that were based on aerial photos taken in 1994, 1995, 2000 and 2001. (Aerial photographs are not taken annually but aerial surveys or counts have been conducted since 1948.) He said that photos, for the most part, matched up with where spawning typically is seen in the vicinity.
- The key word in the question is "impact." Geist indicated that he and other Pacific Northwest National Laboratory (PNNL) staff had conducted extensive substrate surveys, including sediment cores and surface substrate images. However, he had not done any kind of sediment tracer study to show that the fine particles that might be seen during substrate surveys conducted downstream from the White Bluffs landslides were indeed coming from the landslides. He said that if one were trying to assign potential risk or potential mitigation measures, it would seem prudent to be able to say that the sediments in those spawning beds were coming from the landslides themselves and not from somewhere upstream.
- No good pre-landslide data set exists to compare with a post-landslide data set.
- Geist has collected sediment cores from the Hanford Reach, the Hells Canyon Reach of the Snake River, and the Snake River upstream of Hells Canyon Dam. The percent fines in the cores done in the upper Hells Canyon Reach are 4-5%; the percent fines in the Reach in spawning areas are 10-12%. In non-spawning areas, especially downstream in the Savage Island area, fines can be as high as 25-30%. Geist has done detailed analysis on those fines in terms of their gravimetric weight and volumes but not to identify the source. He said he could imagine they were White Bluffs Ringold Formation fines, but, typically, they collect in areas where fall chinook salmon spawning does not occur. Usually fines settle out where velocities are below the preferred fall chinook salmon spawning velocities. In areas where velocities are sufficient for fall chinook salmon spawning and fines also occur, it is not apparent if the fines are precluding spawning or if other characteristics are involved, or both.

- The literature is not specific on percent fines criteria to protect survival of eggs to emergence. The results are all over the map; literature data are not conclusive one way or the other. A recent study in *Fisheries* magazine concluded that sediment pore velocities, dissolved oxygen in sediment, and water quality of the sediment must be considered. One cannot apply a blanket percentage of fines and expect to see a clear relationship between increasing fines and decreasing survival. It is impossible to take anecdotal data and reach any conclusions.
- The group had questions about the feasibility of tracing the sediments. Would not the sediment that has accumulated from high flows along the White bluffs over the years have the same signature as the sediment from the landslide? Would it be possible to trace the sediment back to the landslides as the source?
- Participants concluded that there is not a good answer to this part of the question. The only study that looked at spawning habitat specifically to determine if fines from the uplands were impacting salmon spawning habitat was the WB 10 Wasteway failure at River Mile 370. (The wasteway failed and sluiced out the whole slope, dumping a lot of sediment into the River.) At the request of USBR, PNNL ran transects across the River using an underwater video camera in areas upstream and downstream of the failed wasteway to compare percentages of fines on the riverbed surface. PNNL saw some differences but they were not significant. Impacts to spawning areas could not be quantified. The study team did see increased fines downstream from the failure but did not know if they had direct impacts on the spawning areas at River Mile 368.
- If one were to try to evaluate an effect of the landslides on the physical habitat of the Hanford Reach, it would be important to look at other native species than anadromous fish: Pacific lamprey, white fish, suckers, and minnows. Siltation could benefit Pacific lamprey, which have rarely been found in recent years. It would also be important to look at the impact on the ecology of the river (primary production, macro invertebrates, all the way up the food chain to the glamour species, like the fall chinook) because every aspect of the physical habitat that is affected would have some meaning for the species that use it.
- There is less sediment movement through the Hanford Reach now than there was prior to the construction of Priest Rapids Dam. Large flood events have been greatly reduced by the construction of upstream storage dams, further decreasing sediment movement through the Hanford Reach. For similar reasons, as well as logging practices, there is less woody debris recruitment. Historically, hydrographs between 1800 and 2000 show there is less sediment recruitment because of dams. There may be less sediment movement through the Hanford Reach now than there was 200 years ago.
- The sediment plume on the east side of Locke Island is a localized phenomenon. Below the power lines, that sediment plume clears up and is no longer seen. On the other side of the river, there is no sediment plume.
- The extent of the sediment load coming from the landslides is unknown. For example, researchers have not looked to see how much comes from Priest Rapids vs.

how much enters below the Locke Island landslides. The plume coming off the toe of the Locke Island landslide is definitely visible as it moves downstream. It tends to settle out in the area around River Mile 359 where the cobble bars have disappeared.

- Historically, people have not worried a lot about the Hanford Reach sediment problem. Sedimentation has been a problem associated more with the Snake, the John Day, and the Willamette Rivers. Except for the anomalous landslides, the Hanford Reach has not had major sediment problems.
- Very little is known about the rate of sediment input into the Hanford Reach, including inflows to the Hanford Reach from Priest Rapids Dam or local inflows from the slumps themselves. Nothing is known about what happens to sediment once it is in suspension and is transported downstream. No one has tried to do a sediment budget and to quantify the different types of sediment movement through the Hanford Reach. That is why it is difficult to answer the questions about whether or not the sediment is silting up prime salmon spawning habitat or if the sediment is affecting the spawning areas further downstream. Anecdotally or qualitatively, one can identify changes to the plan form of the Columbia River or to certain gravel bars where people fish, or changes one sees in photos over time. However, there is no quantitative information about where the sediment is coming from, where it is going, or what it is doing.

Conclusions

- The sedimentology is not understood well enough to know if there is a different signature for different elevations in the profile. So, without additional work, the question cannot be answered.
- From the standpoint of the river, the main effect of the landslides is sediment input so sediment input is a key issue to look at to answer the questions about effects. This seems to be a critical uncertainty. Information is needed, first, to be able to say where the sediment is coming from and, second, where it is going. Once the extent of where it is going and what it is doing is known, then researchers could begin to say something about whether it is going where fish are likely to want to spawn or rear and to quantify the impacts. At this point it is unknown if those sediments are coming from the landslides.
- There is no information at this point to suggest that the sediment is having an impact on survival during the incubation period.
- A bigger impact from the sediments than silting up spawning areas may be the filling in of sloughs and the loss of potential rearing habitat.
- No monitoring program is in place to quantify the effect of the sediment.
- If catastrophic slumping, such as the collapse of the bluffs around the Horn of the Columbia River, were to occur in the future, it would likely result in significant adverse impacts to salmon spawning and rearing areas in the Hanford Reach.

Question 1b: Is sediment silting up prime spawning habitat for fall chinook or other species?

Key Points from the Discussion

- The landslides seem like the most obvious sediment input other than natural erosion of the White Bluffs but researchers have not traced it to the landslides.
- At River Mile 368 one can see the shoreline is moving out toward the redds. Video surveys in that area and mapping the boundary between fine sediment and river gravels and cobbles show that the fine sediment line is next to the redds. The fish spawn next to the fines, but the fines do not seem to go into the redds area. This may be because salmon spawn in areas where the velocities are more than a meter/second. It is unlikely that the fine sediments coming off the Bluffs would be deposited in those areas.
- A 1969 study reported steelhead spawning on the backside of Locke Island. In general, current steelhead spawning in the Hanford Reach is an unknown. Some isolated steelhead redds have been seen here and there. It is not something agencies look for annually. Steelhead spawn in April-May, periods of higher flow, when it is hard to see spawning using aerial photos.
- The results of the annual seining conducted by the Columbia River Intertribal Fish Commission (CRITFC) and the Washington Department of Fish and Wildlife (WDFW) have also led to the conclusion that there is not a lot of steelhead use of the Hanford Reach. In 2001 CRITFC work netted 10-12 juvenile steelhead which is more than the one or two found in a normal year. WDFW also found several. Steelhead use of the Hanford Reach has been scattered and is not well documented.
- In 1997, WDFW began rearing Wells stock steelhead (Upper Columbia River stock) at the Ringold Springs Rearing Facility (RSRF), with the first release of juvenile steelhead occurring in spring 1998. This is a different stock of steelhead from the Skamania that were reared and released until 1997. The Wells stock steelhead have been returning as adults to the Hanford Reach and the RSRF since 1999; spawning information has only been recently collected. The change in stock could also have an impact on spawning in the Hanford Reach as well. The Skamania are bigger fish; it is more likely they would spawn in the Hanford Reach than the smaller Wells stock. Wells steelhead have been documented spawning in the outlet streams to Ringold and Priest Rapids Hatcheries. Some anecdotal information exists of their spawning in the Columbia River near the Ringold rearing facility. In addition to steelhead, coho fry have been recovered in Spring Creek at the RSRF indicating coho spawning is occurring in the small streams within the Hanford Reach. The Yakama Tribe has been releasing juvenile coho into tributaries of the upper Columbia River since 1998 and into the Yakima River for many years. The coho found in the Hanford Reach are most likely strays from these releases. Steelhead and coho are similar in that both often seek out smaller tributaries for spawning.

Conclusions

- In general, the anecdotal information does not suggest that the fines are encroaching on the fall chinook salmon spawning areas; it may be that the fines are picked up by the current and transported downstream. More impacts are seen farther downstream, once the flows start to decrease and sediments begin to fall out, closer to the Richland area.
- The workshop participants did not have adequate information to answer the question about impacts of sediment to spawning beds. Available information does not indicate that the landslides are silting up prime spawning habitat for chinook from the 100 F Area upstream. However, they noted that potential impacts to steelhead are unknown.

Question 1c: Are the number of redds being reduced or relocated?

Key Points from the discussion

- A very large number of fish returned to the Hanford Reach this year. Even with high escapement to the Hanford Reach, PNNL biologists did not notice a change in location of the redds. The redds did not appear to have been displaced from areas which could be expected to be impacted by sediment.
- In 1994, there was a fairly high escapement rate to the Hanford Reach. A lot of areas around Locke Island were fairly well spawned in. There was little area between redds that was not used. In 1995, there were fewer fish, but reoccupation rates in 1995 vs. 1994 were over 90%, suggesting similar areas are used each year. It did not seem like fish were using new areas in 1994; they continued to use the familiar areas. There have been a few new spawning sites on the backside of Locke Island since the landslides began; but there does not seem to have been a displacement from other areas.
- As the Locke Island slump has occurred, it has directed the Columbia River into the island and, consequently, has exposed more gravel on Locke Island itself. As a result, isolated spawning has been seen there which was not seen a decade ago. Consequently, it appears that the slumping has opened up the island to more spawning even though it has also contributed more sediment.

Conclusions

- Based on studies done, the researchers did not know of any spawning areas that had been lost nor had they noticed a change in the location of redds.

Question 1d: Are there negative impacts to spawning areas further downstream?

Key Points from the Discussion

- Observers know there are areas that are filling in downstream of the Locke Island landslide but they cannot say, with certainty, that it is because of the White Bluffs landslides. Work has been done to identify where sediment is accumulating but not where it came from.

- Researchers have noticed that a lot of sediment coming from Locke Island is coarser than sediment from the landslides. It seems the deposits accumulating there are siltier than the sediment coming from Locke Island. It is like clay; the particles are tiny. Little accumulation of sediment of any kind has been seen downstream of Locke Island. The small amount that accumulates in the corner tends to get washed out in the spring. By the power line, the sediment seems to be so fine that it stays in suspension. Even in areas where bedrock is visible and accumulations would be expected, the lack of fines is almost uncanny. Perhaps sediment stays in suspension or migrates into back eddy areas where infilling is occurring.
- At Wooded Island some shifting of very small spawning areas has been observed, but the relative percentage of spawning that occurs there is very low. Perhaps there are some impacts to areas that are not used every year or, perhaps, the lower-quality, lesser-used spawning areas downstream are being lost.

Conclusions

- On the backside of Locke Island, in the shallow section at the lower end, it seems one could tell where the accumulated sediment came from. However, farther downstream, where areas are filling in, it is harder to say for sure.
- Researchers do not have hard evidence but believe that most of the impacts would be to the lesser-used and poorer-quality redds.
- There have been no quantitative studies done to address this concern.

Question 2: How does the current sedimentation rate to the Hanford Reach compare with the "natural" or historic rate of sedimentation?

Conclusions

- Sedimentation rates now and historically are not known. Before the dams were built, there probably was more sedimentation, but at that time there were also big flushing flows. This is not a priority issue.[110]

Question 3: Where do the sediments that are being deposited over the redds in the Locke Island area come from? From the White Bluffs or from further upstream?

Key Points from the Discussion

- This question assumes the sediments are being deposited over the redds. This is not known.

[110] This is not necessarily true, particularly in the long term. Some of the changes resulting from long-term sedimentation (discussed under question 7) are dramatic and may have significant impacts on salmon in the long term. This may not be a function so much of sedimentation but of the lack of flushing flows.

Conclusions

- A research team with a sedimentologist/geologist and river hydraulics person could put tools together to answer the question: if the energy of the river were x and the size of the sediments were y, what would happen when the two met? Researchers could sample sediments from various locations in the Hanford Reach and tie them through sedimentology to their source to help to answer the question.

- The group's recommendation to do a quantitative evaluation (see Recommendations below) would address this question.

Question 4: Does the scouring effect of the higher river flows between Locke Island and the landslide cancel out the increased sediment load to the Columbia River from the landslide debris that reaches the Columbia River? What happens further downstream?

Key Points from the Discussion

- There has not been a big collection of surface fines. It seems the fines are settling out at stream bank areas where there are back eddies, sloughs and back channel areas. In the last few years, researchers have seen sloughs filling in downstream from the landslides but cannot say for sure where the sediment load is coming from.

- River flow may move sediment from the Locke Island area but it settles out somewhere further downstream, probably before McNary Dam.

Conclusions

- Based on qualitative observations, when flows are not high, the fines can accumulate in the shallow area at the foot of Locke Island. However, substrate surveys suggest the flows wash them back out.

Question 5: What impact, if any, has the increased sedimentation to the Columbia River had on spawning success? How can this be assessed?

Key Points from the Discussion

- Reports in technical literature on both field and lab work indicate that it is very difficult to determine minimum and maximum percent fines levels and tie these levels to survival to emergence. In large open rivers it is hard to assess survival. Researchers have scratched their heads over how to assess survival to emergence in the Hanford Reach because it is such a big river. There are some techniques (putting redd caps there to catch fry as they emerge or artificially putting eggs in tubes or conducting other lab work); with enough time and money, it is a question one could study, but it is not clear anyone knows how to go about this right now.

- Data are lacking to compare pre- and post-landslides rates.

Conclusions

- There is no evidence to show what sedimentation is doing. It may be filling in the shallow water areas that may, in turn, be impacting rearing habitat. Spawning is just one part of the story. It is easy to see why people have concluded that a lot of mud is going into the River and impacting salmon. Based on a qualitative assessment, mass smothering of salmon redds is not occurring. This does not mean that there is not an important effect occurring, but researchers have not observed mass siltation of cobble bars and other areas where salmon spawn because of the nature of the fine sediments. In addition, the velocities where salmon spawn will prevent mass settling out of fine sediments. That is a qualitative assessment.

- If much bigger landslides were to occur in the future, things could change, including changes in the river channels.

Question 6: What is known about possible impacts of sedimentation on the aquatic plant and insect communities along the White Bluffs?

Key Points from the Discussion

- As a river ecologist one could visualize how to document changes in the physical template of the Columbia River, whether it is increased sedimentation, or changes in areas fish might spawn in, or reductions in backwater sloughs where they rear, or changes in sediment composition that result in different plant communities growing in those areas. Those things could be monitored.

Conclusions

- Based on current information, the researchers did not know the answer to this question.

Question 7: Is there an impact of sediment on the physical structure or template of the river that would cause a change in ecology?

Key Points from the Discussion

- The impacts to the channel have been substantial near Homestead Island where landslides have occurred in the ravines and brought sediment all the way across the channel.

- There are actually two parts to the question about the physical structure of the river. In addition to the physical part, there are changes researchers might quantify in the physical parameters to determine whether or not the changes extend to other parts of the ecosystem, from invertebrates on up. Could researchers answer this question? The answer is yes, starting qualitatively. There has been a change in the plan form of the river: islands have been lost and width-to-depth ratios have changed. Old photos show cobble bars by the old Hanford boat ramp on the left bank that are now gone. Through succession and encroachment of plants with deposition of fines, there are no more cobbles at River Mile 360-61, just upstream of Savage Island. Loss of the cobbles is a result of sedimentation but it is not known if the sedimentation is a result of the landslides or natural sedimentation.

- Photos from the 1960s show a cobble bar at River Mile 360-361 with cobbles as big as softballs, extending as far as one could see out into the river. A1990 photo from the same location shows only grass and willows. Sediments have deposited and plants have grown. Normally one sees a lot of salmon in those cobble-type habitats that are being lost. That is certainly bad for salmon.
- This result could also be because of the absence of springtime flood flows, because of the dam pools upstream. Possibly, it is a combination of both causes. The combination of the White Bluffs landslides without the springtime high flushing flows has created a double whammy.
- Actually there is some flushing as a result of hydropower. In natural river conditions, a 10% fluctuation in a 24-hour period is uncommon. As a result of power generation, fluctuations in this river system can range from 50 to 75 to 100%. Daily fluctuations occur but the big spring flushing effect no longer occurs.[111]

Conclusions

- Rather than focusing on the impacts of the slides on the ecology, it may be better to look at the impact of the landslides on the physical structure or template of the river. If researchers can show a shift in that, it would provide a link to the ecology template. Through that process, changes could be shown to occur. For example, one could document a link to primary productivity because of a loss of gravel substrate.
- This approach would let researchers document what is happening today even in the absence of information about historic rates of sedimentation.

Question 8: What impact have fluctuations (annual and daily) had on erosion and sedimentation in the Columbia River?

Key Points from the Discussion

- From a big picture perspective, the effect of river fluctuations on erosion of the bank is not a major contributor to the sloughing. However, it is significant at Locke Island, where salmon spawn. There may be as much volume of sediment coming into the river from Locke Island as there is from the landslide. Fluctuations of from one to twelve feet on a sandy bank are significant.
- In the Locke Island area, researchers have seen an effect as the land dries, cracks and falls. When flows rise, the water goes all through the upper end of Locke Island. The drying/wetting effects on a daily basis are assumed to have an effect on the island itself, not on the landslides. However, if the landslide were not pushing against the island, there would not be such a big effect.

[111] Reviewer's Comment: Daily fluctuations should not be equated with "flushing flows" unless they reach very high levels (>400 kcfs). A flushing flow is a large flow that flushes out sediment. Except for the 1997 floods, there have been precious few since upstream storage dams were completed in the early 1970s.

Conclusions

- Researchers think the fluctuations contribute some effects but the effects are relatively minor except in periods of high flow.
- Researchers who look at groundwater and geomorphology should not discount the impact of erosion at Locke Island.

Recommendations

1. Establish a baseline, now, for the future so that if there were a catastrophic increase in slumping, there would be data to compare effects. The baseline should include:
   - Metrics that can be compared over time, such as:
     - Monitoring fall Chinook redd locations and possible changes in those locations
     - Monitoring steelhead redd locations
     - Measuring sediment composition, water quality
     - Measuring for aquatic vegetation that can slow water velocity and cause sediments settle out. For example, is milfoil spreading due to natural conditions or is sedimentation contributing?
     - Measure for landslide sediment impacts on sloughs and conduct surveys of both benthic and aquatic life
   - Aerial photographs taken at regular intervals that can be used with different visualization tools. For example, one can turn photos into three-dimensional views of the river and its banks. If cross sections were strategically placed at various locations, one could measure sediment composition; water quality in sediments; surface water and flow water velocities; sediment pore water velocities, and seepage rates.

2. Provide opportunities for researchers working on the landslides, the river, and fish habitat to share information about the geomorphology and the hydrogeology of the river and how the landslides and the river interact.

Appendix A

Glossary

-
- **Bureau of Reclamation:**
  A federal agency established in 1902 that has constructed dams, power plants, and canals in 17 western states, including Washington, to produce electrical power and provide water for irrigated agriculture. (USBR website)

- **Canal:**
  "An artificial watercourse of relatively uniform dimensions, cut through an inland area, and designed for navigation, drainage, or irrigation by connecting two or more bodies of water; it is larger than a ditch." (Glossary of Geology, p. 93)[112]

- **Columbia Basin Project:**
  Managed by the U.S. Bureau of Reclamation, the Columbia Basin Project was started in the early 1930's in an effort to provide irrigation water to the fertile but arid lands of the Columbia River basin in Central Washington. The extensive network of canals, tunnels, reservoirs, and pumping plants which make up the project currently provide water to over half a million acres.

- **Confining bed:**
  "A body of relatively impermeable or distinctly less permeable materials stratigraphically adjacent to one or more aquifers." (Glossary of Geology, p. 134)

- **Columbia Basin Groundwater Management Area (GWMA):**
  Founded in 1997**,** the Columbia Basin Groundwater Management Area or GWMA is a pro-active, voluntary, local planning effort to reduce nitrate in groundwater, and is intended to lessen the need for mandated control measures through the creation of a groundwater management plan to reduce nitrate levels in the groundwater of the GWMA.

- **DNR:**
  Washington State Department of Natural Resources

- **DOE:**
  US Department of Energy

- **FWS:**
  US Fish and Wildlife Service

- **Groundwater:**

[112] All Glossary of Geology references are from the fourth edition of this publication that was edited by Julia A. Jackson and published by the American Geological Institute in Alexandria, Virginia, 1997.

"(a) That part of subsurface water that is in the saturated zone, including underground streams…. (b) Loosely, all subsurface water as distinct from surface water." (Glossary of Geology, p. 284)

- **Groundwater recharge:**
  The flow to groundwater storage from precipitation, infiltration from streams, and other sources of water. (USBR website water glossary)

- **Irrigation:**
  Application of water to lands for agricultural purposes. (US BOR website water glossary)

- **Irrigation districts:**
  A quasi-governmental agency chartered by the state to deliver water under contract with the United States and to operate and maintain federally-constructed facilities. In the Columbia Basin, irrigation districts act as the fiscal agent for the repayment of the construction charges for the Columbia Basin Project. The districts pay for operation and maintenance costs of the reserved works attributed to irrigation. (Hanford Reach of the Columbia River. Comprehensive River Conservation Study and Environmental Impact Statement. Final – June 1994, Vol. I, p. 65)

- **Landslide:**
  "A general term covering a wide variety of mass-movement landforms and processes involving the downslope transport, under gravitational influence, of soil and rock material en masse. Usually the displaced material moves over a relatively confined zone or surface of shear. The wide range of sites and structures, and of material properties affecting resistance to shear, result in a great range of landslide morphology, rates, patterns of movement, and scale. Landsliding is usually preceded, accompanied, or followed by perceptible creep along the surface of sliding and/or within the slide mass. Terminology designating landslide types generally refers to the landform as well as the process responsible for it, e.g., rockfall, translational slide, block glide, avalanche, mudflow, liquefaction slide, and slump. (Glossary of Geology, p. 357)

- **Lacustrine deposit:**
  Material deposited in lake water and later exposed either by lowering of the water level or by uplifting of the land. These sediments range in texture from sands to clays. (Canadian Soil Information System Glossary)

- **Laterals:**
  Small canals that bring water from the major conveyance system canals to fields for irrigation

- **Lining:**
  Protective covering over the perimeter of a conduit, reservoir, or channel to prevent seepage losses, to withstand pressure, or to resist erosion. (USBR website water glossary)

- **Operational water:**
  Clean water added to an irrigation conveyance system to maintain the necessary hydraulic pressure to keep water moving throughout the system

- **Perched groundwater:**
  "Unconfined groundwater separated from an underlying main body of groundwater by an unsaturated zone." (Glossary of Geology, p. 475)

- **Perched water:**
  "Perched groundwater" (Glossary of Geology, p. 475)

- **Perching bed:**
  "A body of relatively impermeable rock that supports a body of perched groundwater. At a given place there may be two or more perching beds and bodies of perched groundwater, separated from each other and from the main zone of saturation by unsaturated zones." (Glossary of Geology, p. 475)

- **Percolation:**
  "(a) Slow laminar movement of water through small openings within a porous material….Also used incorrectly as a synonym of "infiltration…. (b) In the unsaturated zone, the flow of water that has infiltrated and is moving downward or laterally toward the water table." (Glossary of Geology, p. 475)

- **Permeability:**
  The ease (or measurable rate) with which gases, liquids, or plant roots penetrate or pass through a layer of soil or porous media. (US BOR website water glossary)

- **Scarp:**
  "A line of cliffs produced by faulting or by erosion. The term is an abbreviated form of escarpment, and the two terms commonly have the same meaning, although "scarp" is more often applied to cliffs formed by faulting…. (b) A relatively straight, clifflike face or slope of considerable linear extent, breaking the general continuity of the land by separating surfaces lying at different levels, as along the margin of a plateau or mesa. A scarp may be any height. The term should not be used for a slope of highly irregular outline." (Glossary of Geology, p. 570)

- **SCBID:**
  South Columbia Basin Irrigation District

- **Sedimentation:**
  Deposition of waterborne sediments due to a decrease in velocity and corresponding reduction in the size and amount of sediment which can be carried. (USBR website water glossary)

- **Seepage:**
  The movement of water into and through the soil from unlined canals, ditches, and water storage facilities. (USBR website water glossary)

- **Slope:**
  Degree of deviation of a surface from the horizontal, usually expressed in percent or degrees. (USBR website water glossary)

- **Slough/Sluff:**
  "Small avalanches, commonly only referring to small, loose snow avalanches." (Glossary of Geology, p. 599)[113]

- **Slump/Slumping:**
  "(a) A landslide characterized by a shearing and rotary movement of a generally independent mass of rock or earth along a curved slip slope (concave upward) and about an axis parallel to the slope from which it descends, and by backward tilting of the mass with respect to the slopes so that the slump surface often exhibits a reversed slope facing uphill. Syn: slumping. (b) The sliding down of a mass of sediment shortly after its deposition on an underwater slope; esp. the downward flowage of soft, unconsolidated marine sediments, as at the head or along the side of a submarine canyon…. (c) The mass of materials slipped down during, or produced by, a slump." (Glossary of Geology, p. 600)

- **Slump block:**
  "The mass of materials torn away as a coherent unit during slumping. It may be 2 km long and as thick as 300 m." (Glossary of Geology, p. 600)

- **Sprinkler irrigation:**
  A method of irrigation in which the water is sprayed, or sprinkled, through the air to the ground surface. (USBR website water glossary)

- **Unconsolidated material:**
  "(a) A sediment that is loosely arranged or unstratified, or whose particles are not cemented together, occurring either at the surface or at depth. (b) Soil material that is in loosely aggregated form." (Glossary of Geology, p. 689)

- **Wasteways:**
  Canals in an irrigation conveyance system that collect operational water and water returned from irrigated fields

[113] The definitions for "slough" related to wetlands, small marshes, and other such areas.

Appendix B

Letter of Invitation

U.S. Fish & Wildlife Service
Hanford Reach National Monument
3250 Port of Benton Blvd.
Richland, WA 99352

(509) 371-1801
(509) 375-0196 fax

Hanford Reach National Monument
Federal Planning Advisory Committee

Date

Addressee
Affiliation
Address
City State Zip

Dear

As chair of the Hanford Reach National Monument Federal Advisory Planning Committee, I'm writing to invite you to participate in an important interview process related to the landslides and sloughing of the White Bluffs. This Committee was established in 2001 to advise the U.S. Fish and Wildlife Service (US FWS) and U.S. Department of Energy (US DOE) in preparation for a long-term management plan for the Hanford Reach National Monument Comprehensive Conservation Plan.

We have created subcommittees to work on specific aspects of the Monument. The Ad-Hoc Subcommittee chaired by Benton County Commissioner Leo Bowman, has taken on the task of coordinating a process to address a key, contentious issue relative to the Monument: the sloughing of the White Bluffs.

Triangle Associates, which is facilitating the full Committee's work, has been selected to conduct an assessment of this issue. Their job will be to conduct interviews, review studies, and based on the findings, to prepare an assessment report that recommends a process for how to address the issue. The subcommittee will forward the results of the assessment to the full Committee for its consideration. Only after the full Committee has reviewed and approved the assessment report from the subcommittee will this advice be provided to US FWS and US DOE.

You have been identified as someone who may be able to provide valuable input to this assessment. Vicki King of Triangle Associates will call you in the next week or so to schedule an interview; I hope you will agree to participate. The kinds of questions and issues she will want to discuss with you are enclosed. The interviews will be confidential so you can speak freely and candidly.

If you have questions about this assessment or the subcommittee's role in coordinating the assessment with the work of the larger Committee, please ask when Vicki calls. Or, you can call subcommittee chair Leo Bowman at his Benton County office (509 736-3080).

Thank you for your attention and your cooperation.

Sincerely

Jim Watts

Jim Watts, Chair
Hanford Reach National Monument Federal Planning Advisory Committee

Appendix C

Interview Questions

The questions that follow represent the range of issues that Vicki King will want to explore in the oral interviews (in person or by telephone) relative to the sloughing of the White Bluffs. The first set of questions relate to history; the second ask for advice on how best to go about resolving the sloughing of the White Bluffs. Some questions may be more relevant to you than others. You do not need to prepare formal responses before the interview.

1. Please describe the history of your (or your organization's) interest/involvement with the sloughing of the White Bluffs.
2. What's your understanding of the history of landslides and sloughing of the White Bluffs historically, in the years prior to the arrival of settlers in the Hanford area?
3. How has the availability and use of water in the area changed over the years? What was the situation before World War II? What changes have occurred since the Columbia Basin Irrigation Project was developed?
4. Are you familiar with the planning process for the Columbia Basin project in the early days? If so, what was initially planned (specific land areas) relative to what was actually built? Do you know why the full plan was not developed? When was the decision made to build part but not all of the project and who made this decision? What is your best guess as to the likelihood the full project will be built? If it were to be, what do you think the impacts to the Monument might be?
5. What plans or proposed projects in the region are you familiar with that could have an impact on the White Bluffs? What kind of impact do you think these plans or projects would have on the White Bluffs, if implemented?
6. What is your understanding of the causes of the sloughing of the White Bluffs?
7. What is your understanding of the problems caused by the sloughing of the White Bluffs?

Now, I'd appreciate your advice on approaches to resolve the sloughing of the White Bluffs.

8. What information do you feel people who are interested in resolving this issue should have in common?
9. What are the technical issues over which there may be disagreement?
10. Are you aware of studies that have been conducted about the sloughing problem? In your mind, which are particularly useful and why?
11. Are there other questions you feel need to be explored or studies conducted to help resolve the sloughing issue? If so, what are they?

12. Are there technical experts whose advice/opinions would contribute to resolving this issue?
13. Are you aware of any problems similar to the White Bluffs elsewhere in the country (where introduced water has contributed to sloughing)? If so, do you know what they have done in response? Are there any solutions from that case that should be investigated for relevance to the White Bluffs?
14. What suggestions do you have for how to go about developing a recommended solution to the sloughing issue -- in terms of a process. That is, what is your advice for how to approach resolving this problem? Who needs to be involved?
15. Are there other people or organizations we should talk to in order to get an understanding of the issues or advice on how to resolve it?

Appendix D

List of Those Interviewed for the White Bluffs Landslides Assessment

Elected Officials

- Rep. Hastings' Office, Joyce Olson
- Leroy Allison, Grant County Commissioner
- Leo Bowman, Benton County Commissioner
- Frank Brock, Franklin County Commissioner

Native American and Tribal Government Representatives

- Rex Buck, Wanapum Band
- Adeline Fredin, Confederated Tribes of the Colville Reservation
- Aaron Miles, Nez Perce Tribe
- Armand Minthorn, Confederated Tribes of the Umatilla Indian Reservation
- Harry Smiskin, Yakama Indian Nation

Agency Representatives

Bureau of Reclamation

- Doug Bennett
- Bill Gray
- Dan Hubbs

Franklin Conservation District

- Mark Nielson
- Franklin, Grant, Adams Groundwater Management Area
- Paul Stoker, Executive Director

US Geological Survey

- Brian Drost
- Robert Schuster, retired

US DOE

- Lloyd Piper

US Fish and Wildlife Service

- Don Anglin, Supervisory Fishery Management biologist
- Greg Hughes, Project Leader

WA Dept. Fish and Wildlife

- Jeff Tayer, Regional Director
- Paul Hoffarth, Fisheries

Environmentalists

- Richard Leaumont, Columbia Basin Audubon Society

Agricultural Community

- Bryan Alford, South Columbia Basin Irrigation District Board and Farmer
- Al Haymaker, Orchardist
- Shannon McDaniel, Exec. Director, South Columbia Basin Irrigation District
- Mel McInturf, Orchardist
- Dave Morgan, Orchardist
- Tiny Huntzinger, Orchardist
- Tom Solbrack, Farmer

Scientists/Contractors

- Bruce Bjornstad, PNNL
- Dennis Dauble, PNNL
- Steve Reidel, PNNL
- Karl Fecht, Bechtel-Hanford
- Dave Geist, PNNL
- Kevin Lindsay, Kennedy Jenks
- Bob Peterson, PNNL
- Bill Rickert, retired

Other Interested Parties

- Eric Gerber, Advisory Committee member
- Michelle Gerber, Hanford historian and Advisory Committee member
- Tammy Deery, Ringold area resident

Appendix E

Annotated Bibliography of Studies Concerning the White Bluffs, Landslides, and/or Impacts to Fish

- **Bennett, Douglas J., 1999, Locke Island landslide [abstract]: Association of Engineering Geologists, 42nd Annual Meeting, September 26-29, 1999, Program with Abstracts, p. 59.**

  This abstract reports on geotechnical field investigations of the Locke island landslide that were undertaken by the Bureau of Reclamation in 1996-1997. The abstract attributes the landslides of the late 1970s and 1980s (which peaked in 1985) above Locke Island to the creation of ponds for wildlife habitat behind the bluffs in the late 1960s and early 1970s.

  Geotechnical field investigations "included geologic mapping, laser topography, total station monitoring points, geophysics, and deep exploration holes. Determination of stratigraphic relationships and groundwater conditions are an essential key for mitigation."

  The abstract reports that, "Investigations concluded that surface water moves vertically through overlying Holocene silts and sands until encountering impermeable clay units of the Pliocene Ringold Formation, where the water moves horizontally resulting in conditions favorable to landsliding. Continued movement can be attributed to toe erosion and head scarp saturation." The landslides displaced an estimated 30 million yards of material.

- **Locke Island Landslide Study. White Bluffs Area. Columbia Basin Project, Washington, US Bureau of Reclamation, Pacific Northwest Region, December 2002. Report prepared by Douglas J. Bennett and Dan Hubbs, Geologists under general supervision of Richard A. Link, Regional Geologist**

  The Bureau of Reclamation conducted a study on the Locke Island landslide "to evaluate the groundwater conditions in the uplands above the landslide and conduct a landslide stability analysis for the Locke Island landslide." (p. ii) The Bureau initiated the study following meetings of the Locke Island Council on February 1996 and May 1997. The Locke Island Council was a multi-agency group that USDOE convened to address the greatly accelerated pace of erosion of Locke Island caused by the spring runoff in 1996 that threatened valuable paleontological, Native American, cultural and historical resources on Locke Island. Prior to the report's release, Doug Bennett (Bureau geologist) briefly summarized the work he conducted on slope stability in an abstract in conference proceedings in 1999. The Report, issued in December 2002, provides documentation on the conduct of the study and presents USBR's conclusions.

The Bureau concluded that the ponds created for wildlife in the late 1960s and early 1970s were located over an old channel, located perpendicular to the bluff face, that was filled with glaciofluvial sediments. This channel appears to have allowed "downward vertical leakage" of water that then moved relatively quickly toward the face of the bluffs. (pp. iii-iv) The Bureau also concluded that "for the currently understood groundwater conditions, continued presence of the landslide debris in its present position is essential for maintaining the stability of the hillside. Without the buttressing effect of the landslide debris, the hillside is considered unstable in terms of landslide activities. Thus the erosional loss of the landslide debris to the Columbia River should be taken seriously." (p. iv) The report noted that although the slide had moved up to 80 feet between 1998 and 2002 (p. iii), landslide movement had progressively diminished since December 1997 (p. 35). The report concluded that, "Because of the presence of the Columbia River and the inevitable loss of material to erosion and scouring by the running water, small but steady, perhaps imperceptible, movements over long periods of time cannot be ruled out." (p. iv)

- **Drost, Brian W., Ebbert, James C., and Cox, Stephen E. Long-Term Effects of Irrigation with Imported Water on Water Levels and Water Quality. US Geological Survey (Water-Resources Investigation Report 93-4060, Tacoma, WA 1993, pp. 1-19.**

This study focuses primarily on Franklin County. (A subsequent report, Changes in Ground-Water Levels and Groundwater Budgets, from Predevelopment to 1986, in Parts of the Pasco Basin, Washington, US Geological Survey, Water-Resources Investigations Report 96-4086, Prepared in cooperation with Washington State Department of Ecology, Tacoma 1997, covers a larger geographic area. However, the study results for the White Bluffs are essentially the same.) It presents a description of the study area (660 square miles of the Pasco Basin); a history of water-resources development from 1909 through the Columbia Basin Project; a description of the hydrogeology of the study area; an analysis of long-term changes in groundwater levels; an estimation of nitrate levels in groundwater; and a discussion of geohydrologic factors to consider regarding management of water resources.

The authors concluded that the transformation of the Pasco basin through the large-scale importation of surface water for irrigation had come at a price: water logging of soils, landsliding, and large concentrations of nitrate in groundwaters. (p.1) In Franklin County, notable changes that occurred after irrigation began in the Pasco Basin in the 1950s included a rise in groundwater levels by an average of about 200 feet (with increases ranging from 100 to 500 feet, Fig. 6, p. 9) and a sevenfold increase in the annual flow through the groundwater system from pre-development time to 1986 (p. 13). The authors noted that the total increase in groundwater storage was nearly five million acre-feet of water and that recharge from canal seepage and applied irrigation accounted for almost 90 percent of the increase in inflow to the groundwater system and the rise in water levels. (p. 13) They also concluded that nitrogen fertilizers were the primary source of the nitrate, concentrations of which had increased by as much as two orders of magnitude over pre-irrigation values. More than 30% of the sampled wells yielded concentrations of nitrate greater than the drinking-water standard. (p. 1)

The report concluded that, “more efficient irrigation practices and increased use of liners in irrigation canals could significantly reduce the recharge to the groundwater system. This in turn would lead to a lower water table and consequent decrease in the need for buried drain systems. However, decreased canal seepage would lead to significant increases in nitrate concentrations in groundwater. More efficient application of fertilizers would lead to lower nitrate concentrations.” (p. 18)

- **Drost, B.W., Cox, S.E., and Schurr, K.M. Changes in Ground-Water Levels and Ground-Water Budgets, from Predevelopment to 1986, in Parts of the Pasco Basin, Washington. US Geological Survey, Water-Resources Investigations Report 96-4086, prepared in cooperation with the Washington State Department of Ecology, Tacoma, WA 1997.**

  This study covers a larger geographic area than the previous study, but the results for the White Bluffs area are essentially the same as those reported in the study described above.

- **Ebbert, J.C., Cox, S.E., Drost, B.W. and Schurr. K.M. Distribution and Sources of Nitrate, and Presence of Fluoride and Pesticides, in Parts of the Pasco Basin, Washington, 1986-88, U.S. Geological Survey, Water-Resources Investigations Report 93-4197.**

  This study, which includes three large maps, focused on water quality. Of relevance for the White Bluffs was a statement in the abstract (p.1) that canal seepage makes up about 50 percent of the groundwater recharge in the study area (eastern Benton and western Franklin Counties).

- **Hays, William H. and Schuster, Robert L. Evidence of Tectonic Stability Along the Middle Columbia River, Washington, in Quaternary Time. Open File Report 83-365, pp. 1-8.**

  This study investigated outcrops and Pleistocene-age surfaces along the Columbia River, between Priest Rapids Dam and Richland, to assess tectonic stability of the area. Based on the absence of appreciable deformation of these surfaces, the report concluded that there had been little or no deformation along much of this part of the Columbia River since these rocks and surfaces were formed. (p. 1)

- **Hays, William H. and Schuster, Robert L. Maps Showing Ground-Failure Hazards in the Columbia River Valley between Richland and Priest Rapids Dam, South-Central Washington, US Geological Survey.**

Map A: "Generalized geologic map emphasizing ground failures and units susceptible to failure," with extensive narrative describing the map units and the ground failure hazards. Map B: "Active landslides, landslide-susceptible areas, and evidences of tectonic stability," with photographs of landslides.

This summary focuses on information from these maps and narratives relative to landslides of the White Bluffs along the Columbia River. (The maps and narrative also present information about landslides that have occurred inland and east of the White Bluffs and about landslides in the Yakima Basin.)

Map A narrative describes the general setting; the geologic processes that created the White Bluffs and surrounding terrain; and landslides at the following locations, from south to north, as follows:

- ***Johnson Island***: This landslides totals about 90 acres, of which 50 acres are landslides that are currently active or have been active since 1970. The remaining 40 acres are classed as "inactive." The study concluded that "Landslide activity in this area since about 1970 has been caused by seepage of irrigation water from fields just east of the bluffs. Recent activity has resulted in closure of the county road at the base of the bluffs. In addition, development of an orchard on a bench within the bluffs was canceled because of instability of the slope." According to the authors, field evidence indicated a high potential for future major landslide activity in the area.
- ***Homestead Island***: The study noted that landslides in this area were nearly all currently active or had been active since 1970; they included a total of about 44 acres. These slides were also caused by seepage of irrigation water from fields adjacent to the bluffs and from the Ringold Wasteway. Landslides had completely destroyed a former county road at the base of the bluffs. In addition, in the late 1960s a large concrete flume carrying waste water from the Ringold Wasteway to the River was destroyed by landslide activity. "The water that activated the landslide undoubtedly leaked into the bluffs from the wasteway, and water from the wasteway is causing current minor activity. Presently (1983) active landslides in this area pose only minor local hazard to irrigated fields adjacent to the bluffs."
- ***Savage Island***: In this study, the landslides here were second only to Locke Island in size and degree of recent landslide activity. A large landslide mass affected about 104 acres, with a volume of about 13 million square yards; it became active after 1970. "Current slope instability here is attributable to irrigation of fields back from the rim of the bluff, both directly adjacent to the retreating head scarp and farther east. Considerable seepage from the landslide mass forms small creeks, which become ponded on the slide mass and at its toe. There has been considerable new landslide activity since this study began in 1980. As long as irrigation is continued at the present level on the upland adjacent to the landslide, it is to be expected that failure will continue to encroach upon the agricultural land."
- ***Hanford Power Line Landslide Area*** (opposite the former Hanford townsite) – inactive slides from centuries before are found in this area; they have not been reactivated because there is no irrigated agriculture above it. However, the authors attributed the active landslides in the northern part of the stretch between Hanford

Powerline Landslide Area and Locke Island here to seepage from an irrigation wastewater pond 2 miles east of the bluffs. (This is known as the ***WB 10 Pond***.) These landslides were not yet damaging "because the area is undeveloped and because they are not yet large enough to flow into the river. However, until irrigation-water seepage from the east into the bluffs is stopped, landslide activity will probably continue along this stretch of the river."

- ***Locke Island***: Between 1975 and 1987 (the report date), the Locke Island landslide area "vied with the Savage Island area for consideration as the most unstable and active area studied….Debris from the landslides that enters the river is eroded by the swift current around the outer perimeter of the major bend in the river here." Since 1975 the authors said that seepage of irrigation waste water out of the bluffs, principally at the contact between the Ringold Formation and glaciofluvial sands, was what had promoted landsliding." Because of the landslide danger along the White Bluffs here, the area just to the east had not been opened to irrigation. However, water had seeped into the bluffs from irrigation wastewater channels and storage ponds in sagebrush country about 1 mile east of the bluffs. There was a lag time of several years between initial filling of these ponds in 1969 and markedly increased seepage at the bluffs in late 1974 or 1975. Wastewater inflow to the ponds, sharply reduced after seepage in the bluffs was noted, had since been almost eliminated. The authors speculated that within a few years, the seepage and resulting landsliding in this segment of the bluffs might cease.

The authors concluded that the landslides at Locke Island had caused no direct economic loss because there had been no development along the east shore of the river in the Locke Island area. The main indirect loss "has been the disturbance of anadromous-fish spawning beds by landslide deposits and siltation in this last free-flowing stretch of the Columbia River in eastern Washington. The effects of this disturbance are difficult to evaluate; they may not be economically significant." They also concluded that "there [was] a low probability of a slide large enough to block the Columbia River channel northeast of Locke Island, and an extremely low probability that a slide could black the main channel southwest of Locke Island. If waste-water seepage can be effectively prevented, the probability that the channel northeast of Locke Island could be blocked is, likewise, extremely low."

The authors conjectured that, "with continuous irrigation, areas of the bluff wetted by seepage will be subject to landsliding wherever slopes exceed about 15 degrees and, on lesser slopes, wherever the surficial material is old landslide debris.

- **Johnson, R. L., Evaluation of Substrate Condition Near Fall Chinook Salmon (Oncorhynchus tsawytscha) Spawning Sites on the Hanford Reach, Columbia River, (Review Copy) prepared for the US Bureau of Reclamation, Pacific Northwest Laboratory, June 1994.**

The author undertook an underwater video study to assess possible impacts to salmon redds downstream from sediment dumped into the Columbia River at about river mile 370 when the Wahluke Branch #10 (WB 10) wasteway return canal broke on July 19, 1993 and severely damaged the Wahluke boat ramp access road on the Franklin County side of the River. Using two control sites upstream of the damage, the study looked at three different locations below the break along the Hanford Reach, ending above the old Hanford Townsite. (The study area extended nine miles in all.) The study concluded that "There was no obvious difference between the condition of the substrate above the Wahluke Branch #10 impact area … and below the impact area…. This analysis was qualitative and limited to the superficial channel substrate layer." With the exception of the left bank side of Locke Island (upriver of the break), none of the areas upriver or downstream of the break showed "substantial degrees of embeddedness, although turbidity was higher on the left bank side (the side of the impact) than on the right bank side of the channel. The author said this difference could have been related to the "sloughing of the White Bluffs immediately upstream from the impacted area." On the left bank side of Locke Island (2A in the study), the author noted that gravel, cobble, and boulder materials had more than 75% of their surface covered by fine sediment. (p. 10); furthermore, the left bank side in that location was "largely composed of silt, sand, vegetation patches, and Ringold Formation. (p. 14)

- **Lindsey, Kevin, The Miocene to Pliocene Ringold Formation and Associated Deposits of the Ancestral Columbia River System, South-central Washington and North-central Oregon. Washington Division of Geology and Earth Resources, Open File Report 96-8, November 1996, pp. 1-45 and Appendices.**

  "This report describes the stratigraphy and sedimentology of the Ringold Formation and its relationship with correlative units in the region." (p. 1) It "presents a compilation of Ringold Formation geologic information gathered during … studies at the Hanford Site and in much of the surrounding area….This data set is used to establish the basic geologic characteristics of the Ringold Formation, identify in detail the sedimentary facies comprising the Ringold Formation, and determine physical properties of Ringold sediments." (p. 10)

  "Regionally, the Ringold Formation consists of interbedded, unconsolidated to cemented clay, silt, sand, and granule to cobble gravel….Exposures of the Ringold Formation are present in: (1) the White Bluffs adjacent to the Columbia River (Fig. 4), (2) on Eureka Flat north of Wallula Gap, (3) in the Quincy and Othello Basins north of the Saddle Mountains, and (4) on benches and slopes adjacent to basalt uplifts such as Rattlesnake Mountain, the Saddle Mountains, and the Frenchman Hills (Figs. 1 and 3). At and near the Hanford Site the Ringold Formation is largely restricted to the subsurface, and outcrops are limited to the flanks of the anticlinal ridges, the White Bluffs, and Eureka Flat." (p. 6)

- **Locke Island Erosion Control Feasibility Study. Prepared for US DOE, Richland by Walla Walla District, Corps of Engineers, December 21, 1998.**

  This study was undertaken by the Corps of Engineers to investigate methods to protect Locke Island from further erosion. It did not address stabilizing or controlling the landslide. The Corps of Engineers identified and briefly assessed five alternatives to control erosion, some of which had multiple options, in addition to a no action alternative. The costs ranged from

$13,700,000 to $1,553,000. All of the action alternatives would require approval by regulatory agencies.

In addition to noting the role of the Locke Island landslide in promoting erosion of the island, the report also pointed to another factor that contributes to the erosion of Locke Island -- the increased water velocities and daily river fluctuations from the operation of Priest Rapids Dam. (p. 1)

- **Marratt, W. J. Study of Landslides along the Columbia River in the Block 15 Area of Franklin County, WA, Franklin Conservation District, 1988.**

In 1988, W.J. Marratt of the Franklin Conservation District published a report of his study of the causes of landslides that occurred between 1969 and 1987 along the White Bluffs above the Columbia River in irrigation Block 15 of the Columbia Basin Project. (This complex of landslides is also referred to as the Johnson Island Slide.) The slide area is located in Franklin County between river miles 346 and 347, about 15 miles northwest of Pasco. It grew from a small slump to extend more than a mile and to involve 3.5 to 4 million cubic yards of material.

In his report Marratt attributed the following ***problems*** to the landslides:

- Road closure: Over the decade between 1973 and 1983, landslides covered increasing areas of a county road along the River; in 1983 it was permanently closed.
- Sediment flow into the River: Sediment was measured entering the River at a rate of 31 tons per day (in 1987) which could be damaging fisheries (spawning beds) and other fragile ecosystems downstream. The sediment itself included silt, nitrates, and possibly other contaminants.
- Greater slope instability and a higher likelihood of additional landsliding in the future, and sliding more rapidly, than in the past. This is because the material is more fragmented and the wetted material that breaks through removes support for the subsidence at the toe, which removes the support for the mass of broken material above.
- The potential loss of about 150 acres of agricultural land along the top of the bluff if the entire bluff were to fail.

He identified the following factors as contributing to the landsliding:

- Erosion: The Columbia River is actively eroding the toe of the White Bluffs, undercutting the bluffs. The undercutting would create earthfalls if it were not for the addition of water that is causing slump-earth flow landslides instead of earthfalls.
- The composition of the White Bluffs: The Ringold Formation is resistant to erosion as long as it remains dry and the upper layers are not breached. this same material has little or no structural strength once it is saturated and fails, slumps and flows. Once wetted, impermeable layers are created over which water can travel horizontally in the sandstones. Field investigations showed water flowing from the bluffs at the 600 and 700 foot elevations. It wasn't possible to investigate if water was flowing from the bluffs at lower elevations because of the covering of the slide debris.

- Dramatic increase in the amount of water: In contrast to the 40-year average (between 1945 and 1985) of 7 inches of precipitation per year, irrigation brought to the area the equivalent of about 60 inches of rain per year in the early days of irrigation which decreased to about 40 inches per year by the mid 1980s. The study did not determine if the source of the water contributing to the landslides was from a greatly raised groundwater table (and saturated soil column) or from a perched water table.

The author concluded that lowering the regional water table was key to producing lasting effects and recommended the following measures be taken to reduce the landslide potential in the future:

- Lining four miles of the Potholes Canal with monitoring to assess the impact of lining on the water table and the outflow of water along the slide area. If beneficial, consideration could be giving to lining or piping the laterals and wasteways that feed back into the canal.
- Encourage irrigation practices that are based on effective root depth, soil type and crop consumptive use (in the study area and throughout the region)
- Continue the current SCBID position of not using the Potholes Canal to extend the power generation season.

He also recommended additional steps:

- As a high priority, future monitoring of groundwater wells to note changes caused by modifications of surface activities

- **Mueller, R.P., Geist, D.R. Steelhead Spawning Surveys Near Lock Island, Hanford Reach of the Columbia River, October 1999, pp. 1-11.**

This study was undertaken after the National Marine Fisheries Service listed upper Columbia River steelhead trout as endangered. The purpose of the study was to determine if steelhead spawned in the vicinity of Locke Island erosion and to evaluate the composition of substrate in the affected area. The study team conducted aerial and underwater video surveys to document the occurrence of steelhead redds in the spring of 1999. (Steelhead likely spawn in the Hanford Reach between February and early June, with peak spawning in mid-May. p.1.) No steelhead spawning was documented within the survey area.

In July 1999 the team conducted habitat surveys both in the area adjacent to the erosion zone and upstream. The majority of the survey area was composed of gravel and medium cobble. Aquatic vegetation (milfoil) was found in the upstream section, indicating lower water velocities not conducive to steelhead spawning. Based on the available substrate within the entire survey area, the authors estimated 81% of survey site could be used by adult steelhead for spawning. (p. iii)

The authors concluded, “There is no indication that the material entering the river from the slump is degrading steelhead habitat in the immediate vicinity of the slump. In fact, the slumping may be increasing available habitat by increasing the channel velocities, which in turn scours and clean gravel and cobble substrate. However, we did not survey downstream of the slump; thus, we have no data on whether fine particles settle out once velocities are reduced. This would negatively affect potential spawning habitat further downstream by reducing streambed particle size, which creates detrimental conditions for salmonid spawning. (p.9)

- **Neff, George E. "Columbia Basin Project," in Engineering Geology in Washington. Volume I. Washington Division of Geology and Earth Resources Bulletin 78, 1989, pp. 535-563.**

  This report describes the geologic setting of the Columbia Basin Project, the dams, the canals, landslides, groundwater hydrology, drains, use of project groundwater on non-project land, and off-stream hydropower development. Of particular interest for this assessment are his remarks concerning landslides in the Ringold Formation. Concerning landslides involving the Ringold Formation (p. 553) he said that they occurred "along the Columbia River from 20 mi north of Ringold to 10 mi south of Ringold …. As the Ringold Formation became wetted by the importation of irrigation water on the Columbia Basin Project lands, the wetting of steep slopes left by the channeled scabland flood erosion results in the reactivation of ancient slides and the formation of new ones. The steepest slopes slide suddenly, giving little warning. These slides are large and hazardous. Intermediate slopes fail gradually with movement occurring either on a bedding plane or as characteristic rotational failure. Slopes less than 6 percent are stable."

- **Nickens, P.R., Bjornstad, B.N., Cadoret, N.A., and Wright, M.K. Monitoring Bank Erosion at the Lock Island Archaeological National Register District: Summary of 1996-1997 Field Activities. Pacific Northwest National Laboratory, Richland for US DOE, August 1998.**

  Because of the movement of the Locke Island Landslide in the channel toward Locke Island in the early 1990s, US DOE asked PNNL to monitor erosion on Locke Island. Work began in November 1995 and continued in 1996 – a winter of significantly increased river flows, flows that also continued high over a longer-than-usual period (January to summer). 1996 "was undoubtedly the worst year overall for active bank recession." High runoff occurred again in late winter and spring 1997, which continued the very active erosion cycle begun the preceding year." (p. iii) The study reported a number of important findings about the very valuable cultural and historical resources on the island that were discovered as a result of the monitoring.

  Significant findings for the landslides of the White Bluffs included the following:

  - More than half of the established transects [on Locke Island] experienced severe erosion and recession of the bankline; several of these measured up to 16 meters or more of horizontal loss just in 1996. This resulted in approximately 41,000 cubic meters of sediment entering the river in 1996. It also resulted in extending the length of the eroding bank by 50 meters. (p. iv)

- The landslide had continued its movement into the river channel during the past 10 years. Analysis in the early 1980s by the US Geological Survey indicated that movement of the landslide had stabilized, as a result, in part, to intentional draining of nearby irrigation wastewater ponds. However, comparative analysis and careful measurement of aerial photographs from 1987 to 1996 showed that the lower part of the slide had actually moved another 150 meters into the channel toward Locke Island. This movement had reduced the width of the eastern river channel from 300 to 150 meters over the same period. Before the slide occurred, the channel on the east side of the island was 450 meters wide. (p. v)

- **Powell, Lorraine and Powell, Jack, Memorandum, November 20, 1996, "Landsliding in The Ringold Area" [above Homestead Island]**

This memorandum was prepared by DNR geologists following investigation of a large landslide on November 11, 1996 that impacted state trust land (about five acres) along the east side of the Columbia River near Ringold in Franklin County. The investigation occurred on November 14 and the Memorandum summarizing the findings was prepared on November 20.

After referencing the Schuster and Hays article, "The White Bluffs Landslides, South-Central Washington, in Engineering Geology in Washington, Vol. II, the authors stated that "irrigation of lands along and adjacent to the cliffs [of the White Bluffs] had activated old landslides and triggered new failures." They projected that "This entire half mile long section of State Trust land will continue to slide in the foreseeable future, impacting the Columbia River and hindering development." They speculated further that "a probability exists that this entire section of the White Bluffs could form a single gigantic landslide similar to existing slides located both north and south of this site." They based these projections on the following summary points:

- As long as irrigation continues to saturate the bluffs, old failures will be reactivated and new slides will form.
- Unlined ditches and an undrained wasteway canal located above the cliffs add significant groundwater to the system, which contributes to the sliding.
- The immediate danger to orchards below the landslides include
- – A 50-foot section of hillside 40 feet high that "appears ready to slide down the gully
- – As the cliff sloughs off, it could block the stream in the gully at the bottom, resulting in additional dam break floods that could wash mud into the orchard and/or the bin storage area.
- – While retaining dams have been recently built below two small slides located 1600 feet north of the most recent slide, the authors expect both dams to fail (drainage outlets were not installed at the base of either structure, p. 4) which would result in small earth flows reaching the orchard below.
- – The site is potentially dangerous for anyone walking on or under the recent landslide.
- – "A possibility exists for the entire area to fail catastrophically in a large landslide involving hundreds of acres….This type of catastrophic failure could destroy the

entire orchard area located below the November 11, 1996 landslide and impact both fisheries and water quality in the Columbia River for miles downstream." (pp. 1-2)

They noted that the November 11 slide was one of a number that had recently occurred in this section of the White Bluffs. Three others had occurred in the previous few years. Two other small slides were located north of the recent slide and impacted the orchard access road. A slide nearly as large as the present failure occurred in 1995, south of the November 11 flow, which crossed the easternmost channel of the Columbia River and deposited material on Homestead Island. The largest landslide along this section damaged the Ringold Wasteway spillway, rendering it nonfunctional and destroying the access road to Taylor Flats to the south. That road had not been rebuilt. (p. 2)

Although unable to see the actual slippage surface the landslides were moving along,, the authors concluded the failure was probably along unconsolidated sand beds overlaying an impermeable clay layer. The area abounded with evidence of subsurface water including springs, seeps, substantial vegetation lines, and streams. (p. 3) They also noted that the largest landslide on this piece of DNR trust land had occurred where the unlined Ringold Wasteway emptied into the spillway to the Columbia River.

- **Powell, Lorraine and Powell, Jack, Memorandum, January 23, 1997, "Ringold–White Bluffs Landslides - Update**

The authors revisited the November 11, 1996 Ringold-White Bluffs slide on January 22 to review slide activity on DNR orchard lease lands located below the active slide. They found "the entire slope above the orchard to be unstable and in an extremely hazardous condition. During the site inspection the slope was observed actively moving at the toes of previous landslides, small mud slides were actively undermining slopes, and large areas of the slope are cracked and bulged. Failure of large portions of this slope will occur as thawing and winter precipitation decrease the small degree of remaining internal cohesive strength holding the slopes." (p. 1) The noted that "The Columbia River is actively eroding the delta formed by the debris flows which combine with river currents to send plumes of silt laden water down stream." (pp. 2-3)

- **Schuster, R.L., Chleborad, A.F. and Hays, W.H. Irrigation-Induced Landslides in Fluvial-Lacustrine Sediments, South-Central Washington State, 5th International Conference and Field Workshop on Landslides, Australia, Aug. 12, 1987**

Much of the information in this article can also be found in "The White Bluffs Landslides, South-Central Washington," in Engineering Geology in Washington (described below) and in the article that follows.

- **Schuster, Robert. L. and Hays, W.H. Irrigation-Induced Landslides in Soft Rocks and Sediments along the Columbia River, South-Central Washington state, USA. Fourth International Symposium on Landslides, Toronto 1984 Proceedings, pp. 431-436**

  See the notes for The White Bluffs Landslides, South-Central Washington, in Engineering Geology in Washington, Vol. II, below for a summary.

  Additionally, this study reported that "water seeps into the bluffs [above Locke Island] from canals and irrigated lands several kilometers east and north, and from irrigation waste-water ponds only 1.5 km to the east. It concluded that the ponds were probably the prime source of the seepage during the mid and late 1970s. The ponds were then largely drained in response to the landslides. The authors noted that another waste-water pond about 3 km east of the river [WB10] was contributing to seepage and landslide activity a few kilometers south of the Locks Island area. They concluded that landslide activity was likely to continue in the area "until such ponds are drained and waste water is returned to the river by impervious aqueducts."

  With respect to the potential blockage of the Columbia River by landslides, the authors concluded, "If seepage can be largely eliminated by better control of irrigation and its waste water, there would be practically no chance that even the northeast channel could be blocked." (p. 435)

- **Schuster, Robert.L., Chleborad, Alan F. and Hays, William H. The White Bluffs Landslides, South-Central Washington, in Engineering Geology in Washington, Vol. II, Washington Division of Geology and Earth Resources Bulletin 78, pp. 911-920.**

  (R.L. Schuster indicated this was the most comprehensive of the three articles he co-authored on this topic.)

  The purpose of this paper was to describe selected landslides from a large group of recent irrigation-induced landslides in Pliocene fluvial-lacustrine sediments in the 50-km-long White Bluffs area along the east side of the Columbia River in south-central Washington. After describing the arid climate in the area, the authors noted the eight-fold annual increase in water over natural conditions that had occurred since irrigation began in the area (1953-1964). They then described the Ringold Formation, the distribution of active and inactive slides, and the susceptibility of the Ringold Formation to sliding when wetted.

  They said that the total area of landslides along the White Bluffs was approximately 6.8 hectares, of which 80% were inactive prehistoric slides while 20% consisted of landslides that had moved in the past 15 years. The study then focused on three major landslides from the recent period. Using names of the islands in the Columbia River near the landslides, they designated them as the Locke Island Landslides, the Savage Island Landslides, and the Johnson Island Landslides.

Locke Island Landslides

Located at the north end of the White Bluffs, these landslides differ from those further south in two ways: 1) the bluffs are on an outside bend of the river, which means the base of the bluffs and the toes of the landslides are subject to erosion by the river, and 2) there is no irrigated agriculture within about 8 kms east of the river. However, irrigation waste-water ponds were established within 2 kms of the river to enhance wildfowl habitat. During the late 1970-s and early 1980s, these ponds were the main source of seepage water to the bluffs and thus were a major cause of failure of slopes above the river. In response, the water levels in these ponds were lowered considerably and landslide activity along Locke Island had declined dramatically. However, the landslide had progressed one-third of the way across the northeast channel of the river toward Locke Island. The water causing the landsliding was the irrigation waste water that had seeped to the bluffs from the waste-water ponds either over the relatively impermeable surface of the Ringold Formation or through pervious layers within the formation.

The primary direct loss caused by the landslides had been siltation of spawning beds of anadromous fish in the Hanford Reach. The authors believed that it was very unlikely that a landslide in the Locke Island area would block the Columbia River, even under the worst-case scenario.

Savage Island Landslides

These landslides became active after 1968 and enlarged dramatically after 1980. Unlike Locke Island, these landslides were immediately adjacent to irrigated croplands; they affected about four hectares of irrigated fields. These landslides were about 1 km back from the River and did not flow into the River. The study attributed these landslides to the irrigation east of the bluffs, both immediately adjacent to the retreating head scarp and farther east. Slides were worst when natural precipitation combined with irrigation water to create a critical soil-moisture relationship. The study expected the slides to continue if irrigation continued on the upland adjacent to the landslide.

Johnson Island Landslide

According to the study, only a small percentage of the bluffs in this southern area of the White Bluffs were subjected to recent major landslide activity. However, a few recent slope failures had resulted from irrigation on croplands and fruit orchards immediately to the east of the bluffs; the authors anticipated more such failures. The increased water level in the Ringold Formation (from higher than average precipitation and from irrigation) caused landslide activity along the bluffs in 1979 and 1981 and again in 1985. The authors expected major landslide activity on these slopes to continue if irrigation continued. The landslides had already destroyed a county access road to the area. The authors conjectured that croplands on the edge of the irrigated upland above the slope could be lost in future landslides

Additional Background Information

- **Background for White Bluffs – Hanford Reach, Washington. Nez Perce Tribe ERWM, 6 pp. and a bibliography**

  This report was prepared to support tribal policy-making concerning the proposed Wild and Scenic River designation for the Hanford Reach. It describes the general setting of the Hanford Reach relative to the Hanford Site and radioactive and hazardous wastes found at and around the Site and along the Columbia River. It describes the geology of the Ringold Formation and the susceptibility of this Formation to sliding. It summarizes the active landslides on the Bluffs at Locke Island, Savage Island, Homestead Island, and Johnson Island. It further notes the presence of surface cracks and vertical factures upland of the bluff face that were mapped by a tribal geologist (Paul Danielson). (pp. 1-2)

  The report notes that examination of slide areas reveals the "universal presence of water seeping from the Bluffs in springs and marshes…. There can be little doubt that water is the primary cause for these landslides as verified by the observation of springs, saturated cliff faces, and mud flows."

  It describes the landslide process as follows:

  > *"The water found in the Bluffs reduces the strength, decreases frictional resistance, and adds weight to the unconsolidated Ringold Formation. Because the transmissivity of the Ringold layers varies, water will accumulate in certain sediment layers within the Bluffs. This wet layer is the plane upon which the slide begins. The bluff above a wet layer will slide when the water laden and lubricated layer fails under the weight of the overburden.*
  >
  > *Sources of water on the Bluffs are natural precipitation, irrigated farmlands, irrigation and waste water canals, and irrigation waste water ponds located up slope east of the Bluffs and on Wahluke Slope. Water from these activities percolates through the soil to the Ringold Formation. Some of these layers resist the downward flow of water, forcing it to flow laterally. Since Ringold layers dip toward the Columbia River, water that collects above less transmissive Ringold layers will move down slope toward the Bluffs. Eventually this water will reach the Bluffs and becomes the source of water triggering the landslides." (p. 3)*

  The report identifies a range of hazards from continued landslides: from a closed road to loss of a concrete flume that was part of the Ringold Wasteway (destroyed by the Homestead Island slide in the late 1960s). At Savage Island, irrigated along the top of the bluffs were destroyed. At Locke Island, cultural artifacts were lost because of changes to the river channel and increased erosion. The slides "disturb and destroy salmon spawning beds by siltation." It mentions possible damage to cooling-water intake systems for the Washington

Public Power Supply System Reactor and considers the possible mobilization of contaminants from Hanford in the river and the soil. It mentions as “the most unlikely occurrence” an earthquake triggered, massive slope failure caused by liquefaction of the White Bluffs which would temporarily block the Columbia River. This could endanger Hanford facilities on the west side of the River as well as citizens and property downstream of the temporary dam. This could also mobilize contaminants in the soil column.(pp. 3-4)

The paper concludes that “prohibition of further irrigation on both sides of the Hanford Reach [would] aid in the stabilization of the White Bluffs as [would] a “Wild and Scenic Designation” for the Hanford Reach. Both measures would protect public health and the environment by preventing the remobilization of contaminants buried within the river’s sediment and the shoreline’s soil column and destruction of salmon spawning beds. (p. 5)

- **Gerber, Michele S., Ph.D. The Wahluke (North) Slope of the Hanford Site: History and Present Challenges. Westinghouse Hanford Co. Columbia Magazine (Tacoma: Washington State Historical Society, Winter 1997-98) Vol. 11, #4.**

  This seven-page history focuses on decisions made concerning the Wahluke (North) Slope between the early 1940s and the early 1990s. Of particular interest is the author’s account of decisions about the Wahluke Slope that were made by the predecessor agencies of the US DOE relative to preventing development of the Columbia Basin Project on the Wahluke (North) Slope between 1943 and the mid 1960s. The history also interweaves efforts throughout this period by the US Bureau of Reclamation and local interests (counties and the agricultural community) to allow agricultural developments planned as part of the Columbia Basin Project to proceed. It describes the creation of a “Red Zone” in the former Control Zone (where irrigated agriculture was prohibited) on 14,000 acres of Wahluke Slope after the Bureau of Reclamation conducted drainage tests in 1966-67 that indicated the cost of correcting drainage problems on those acres was not economically feasible. Instead of becoming farmland, the land in the Red Zone was divided into two wildlife preserves: the federally-managed Saddle Mountain National Wildlife Refuge and the state-managed Wahluke Wildlife Refuge. (p. 5) A canal and other irrigation facilities to serve Mattawa and Royal City were authorized to proceed.

  The author notes that approximately half of the million acres that were projected to be developed in the 1940s by the Columbia Basin Project had been. In 1988 the Bureau of Reclamation undertook a large EIS on continued development of the Columbia Basin Irrigation Project. In 1990 the Draft EIS found that public demand and the availability of water from the Columbia River would support no more than development of 87,000 additional acres. In 1994, the Bureau reported that, as a result of new strictures in water conservation and the needs of fish migration, it would not issue a final EIS and it was deferring indefinitely development of even the 87,000 additional acres. (p. 6) The author then describes the debates that were underway at the time of her study on future management of the North Slope: whether as a federally-protected Wild and Scenic River or as a locally-controlled resource for possible development.

- **Pitzer, Paul C. Grand Coulee: Harnessing a Dream. WSU Press, 1994**

  This monograph provides a fascinating history of the construction of Grand Coulee Dam and the role it has played in the history of the Pacific Northwest since its completion. It describes in general terms the history of the Columbia Basin Project, the development of which is of particular interest for the landslides of the White Bluffs. Chapter 13 (To Build or Not To Build) includes an account of the debates that have occurred since the 1970s about the desirability and feasibility (especially the economic feasibility) of bringing additional land under irrigation and "completing" the Columbia Basin Project.

Appendix F

Participants at the Technical Workshops and their Affiliations

Workshop Focus	Participants
Geology/Landslides Tuesday, January 21, 2003, 1 PM – 5 PM	• ***Technical Facilitator***: Robert L. Schuster, US Geological Survey Scientist Emeritus (volunteer, retired)– landslide specialist, Denver, CO • Rex Baum, landslide expert for the US Geological Survey, Denver, CO • Douglas Bennett, engineering geologist, US Bureau of Reclamation, Boise, ID • Katyi Didricksen, hydrogeologist, US Bureau of Reclamation, Grand Coulee, WA • Karl Fecht, geologist at Bechtel-Hanford, Richland, WA • Dan Hubbs, geologist, US Bureau of Reclamation, Ephrata, WA • Kevin Lindsey, geologist, consultant at Kennedy-Jenks, Kennewick, WA • Mark Nielson, Franklin Conservation District Manager, Pasco, WA • Shannon McDaniel, Manager, South Columbia Basin Irrigation District, Pasco, WA (Observer)
Water/Groundwater/Irrigated Agriculture Wednesday, January 22, 2003, 1 PM – 5 PM	• ***Technical Facilitator***: Robert L. Schuster, USGS retired – landslide specialist, Denver, CO • Steve Cox, hydrologist, USGS, Tacoma, WA • Kayti Didricksen, hydrogeologist, US Bureau of Reclamation, Grand Coulee, WA • Dan Hubbs, geologist, Bureau of Reclamation, Ephrata, WA • Kevin Lindsey, geologist, Kennedy Jenks, Kennewick, WA • Shannon McDaniel, Manager, South Columbia Basin Irrigation District, Pasco, WA • Mark Nielson, Manager, Franklin Conservation District, Pasco, WA; • Paul Stoker, Executive Director, Columbia Basin Groundwater Management Area, Othello, WA
Impacts to Fish and Habitat Thursday, January 23, 2003, 1 PM – 4:30 PM	• Don Anglin, fish biologist, US FWS, Vancouver, WA • Jeff Fryer, fish biologist, Columbia River Intertribal Fish Commission, Portland, OR • Dave Geist, fish biologist, Pacific Northwest National Laboratories (Battelle), Richland WA • Paul Hoffarth, fish biologist, WDFW, Yakima, WA • Ken Tiffan, fish biologist, US Geological Survey, Cook, WA

Appendix G

Brief Biographies of Technical Workshop Participants

In alphabetical order

Don Anglin: Biographical information not available.

Rex L. Baum has worked as a geologist in the Landslide Hazards Program of the U.S. Geological Survey (USGS) since 1984. He currently serves as the chief of the USGS Landslide Hazards Project, which is based in Golden, Colorado. Rex received extensive training in geology and engineering geology and was awarded a Ph.D. in Geology from the University of Cincinnati in 1988. Dr. Baum is the author or coauthor of many technical papers and abstracts. He has conducted landslide investigations and research in a wide range of settings at sites in several western states as well as other localities. He has experience in conducting integrated field, laboratory and theoretical investigations of landslide processes, landslide mapping, and in developing methods of assessing landslide susceptibility and hazard. His experience includes investigations of large, deep-seated landslide complexes and the stability of coastal bluffs.

- Education: B.U.S. 1981, University of New Mexico; M.S. 1983, Geology, University of Cincinnati; Ph.D. 1988 Geology, University of Cincinnati

Doug Bennett was raised on a farm in Southern Idaho and currently lives in Boise, Id. Mr. Bennett began his career in precious metals exploration. He has been employed by the U.S. Bureau of Reclamation as an engineering geologist in the Pacific Northwest Region since 1991. He is also a member of the National Association of Engineering Geologists, and is a Registered Engineering Geologist with the State of Washington. Mr. Bennett became involved in the White Bluffs area in 1998. He is the site geologist for the Bureau of Reclamation's Locke Island Landslide Study. He spent two years onsite mapping, drilling and sampling the Locke Island landslide and the surrounding area. His knowledge of the geology and features of the Locke Island landslide have been instrumental in understanding the causes of the slide. He, along with Dan Hubbs (USBR), prepared and released the Bureau's report on the Locke Island Landslide (January 2003).

- Education: BS in Geology and Earth Science Education, Boise State University; MS in Engineering Geology, 1996.

Kayti Didricksen has worked for the US Bureau of Reclamation since 1978 in both engineering and groundwater geology. Her work includes hydrogeologic assessments for water supply, dewatering, assessing interaction between groundwater and surface water, agricultural impacts to/from groundwater, and construction seepage and dewatering studies.

- Education: BS in Geology, Western Washington University; MS in Geology (Hydrogeology), Eastern Washington University

Karl Fecht has been studying the geology, groundwater, and geologic hazards of eastern Washington, northern Oregon, and western Idaho for over 30 years. His primary responsibilities have been providing geology, geohydrology, and engineering geology support to siting of nuclear power plants and waste processing facilities, operation of radioactive/hazardous waste disposal and storage facilities, remediation of contaminated sites and facilities, and monitoring of vadose zone and groundwater. Mr. Fecht is the manager of Environmental Technologies for Bechtel Hanford, Inc. in Richland, Washington.

- Education: BS in Geology, Washington State University.

Jeff Fryer has worked at the Columbia River Inter-Tribal Fish Commission for 13 years, mostly focused on Columbia Basin chinook and sockeye salmon stock identification and escapement estimation projects. For the past 10 years, he has supervised the CRITFC-administered project to capture and tag 200,000 wild juvenile fall chinook salmon in the Hanford Reach.

- Education: Bachelor of Science (Computer Science) and a Master of Science (Computer Science), University of New Brunswick at Fredericton, Canada, Ph.D. in Fisheries, the University of Washington.

David R. Geist is currently Staff Scientist, Ecology Group, Environmental Technology Directorate at Pacific Northwest National Laboratories, Richland, WA. He has been a research scientist at Battelle since 1991. An expert in fisheries behavior and ecology, Dr. Geist is lead scientist and project manager for a number of studies dealing with fisheries issues in the Pacific Northwest. He is currently researching how hydroelectric dams in the Columbia River Basin affect the survival of fish, including chinook salmon, chum salmon, and bull trout. Dr. Geist has published more than 25 papers and reports on a variety of topics related to the ecology and behavior of salmon, with particular emphasis on their spawning habitat selection in large rivers like the Hanford Reach of the Columbia. His experience also includes assessing the impacts of hydroelectric dams on the physiology and behavior of fish using radio telemetry. Before joining Battelle, he was the Regional Habitat Manager for the Washington State Department of Fisheries and a fisheries research biologist with the Upper Columbia Fisheries Center at Eastern Washington University. Dr. Geist is a fellow in the American Institute of Fishery Research Biologists, a member of the American Fisheries Society and an adjunct faculty member at Washington State University. He is also a member of the Federal Advisory Committee advising the US Fish and Wildlife Service on the management of the Hanford Reach National Monument.

- Education: B.S., Biology, Eastern Washington University; M.S., Biology, Eastern Washington University; Ph.D., Fisheries Science, Oregon State University

Paul Hoffarth is a Fish & Wildlife Biologist with the Washington Department of Fish and Wildlife in Benton and Franklin counties, with more than a decade of experience in the Pacific Northwest. He is currently managing anadromous and resident species. He currently supervises staff conducting sport fish sampling for steelhead and fall chinook, fall chinook run reconstruction from carcass recovery, and Priest Rapids and Ringold hatchery evaluation in the Hanford Reach. Paul has supervised the evaluation of juvenile fall chinook stranding on the Hanford Reach for the past three years and has worked with the Hanford Stranding Policy committee to develop a plan for the protection of juvenile fall chinook during emergence and rearing. Paul acts as the WDFW representative on Vernita Bar surveys as part of the Vernita Bar Agreement with Grant County PUD to set critical flows for the protection of fall chinook during redd construction and incubation. He has extensive experience working with juvenile and adult salmonids at mainstem hydroelectric facilities including knowledge of screening, bypass, spill and turbine operations, juvenile fish transportation, fish passage, fish facilities, and thermal stressors associated with mainstem passage. Paul has worked with adult salmonid escapement for coho, steelhead, and fall chinook.

- Education: A.S. in Biology, Volunteer State Community College, Gallatin, TN; B.S. in Fish and Wildlife, University of Tennessee, Knoxville

Dan Hubbs has worked as a Staff Geologist for the USBR in the Pacific Northwest Regional Office since 1974. He was in the Boise, ID office from July 1974 to February 1983. Since then he has worked as the Project Geologist for the USBR in the Columbia Basin Project in Ephrata, WA.

- Education: BS in Geology, Boise State University

Kevin Lindsey is a geologist and hydrogeologist with Kennedy/Jenks Consultants in the Tri-cities. He has over fifteen years of postgraduate experience in geology and hydrogeology, including geologic mapping, geologic databse construction and modeling, geotechnical, vadose zone and groundwater well logging, hydrogeologic characterization and monitoring of sediment and basalt aquifers, and teaching introductory and upper division geology courses. Most of this experience has been gained in the Pacific Northwest as a postdoctoral researcher at Washington State University and the Hanford Site as a private consultant. Dr. Lindsey's post-doctoral research ocused on the nature and origin of the Miocene-Pliocene Ringold Formation in the Pasco Basin. His work has included basalt aquifer mapping and characterization for the Columbia Basin GWMA, Port of Morrow. Dr. Lindsey has a wide range of experience in the physical properties of the region's sediment aquifers which is valuable assessing groundwater quality, quantity, and supply, controls and characteristics of surface water-groundwater continuity, and impacts to shallow groundwater development and mitigation activities.

- Education: B.S. Geology, 1979, University of Missouri-Columbia; M.S. Geology, 1982, Idaho State University; Ph.D. Geology, 1987, Washington State University; Post-Doctoral Research on Ringold Formation, 1989, Washington State University.

Shannon McDaniel has served as Secretary/Manager of the South Columbia Basin Irrigation District from 1990 to the present. The South District operates and maintains irrigation facilities that serve 230,000 acres. The District borders the entire eastern boundary of the Hanford Monument. Mc McDaniel is responsible for all operation and maintenance activities within the District. He has been responsible for system improvements, canal linings, and wetlands. Mr. McDaniel has worked with state, local, and federal agencies on issues relating to land use within the District. He has been engaged in discussions concerning the Hanford Reach since 1990.

- Education: Bachelor's degree in civil engineering, Oregon Institute of Technology in Klamath Falls, Oregon.

Mark Nielson is currently the District Manager with the Franklin Conservation District and has worked for the District since 1987. Mark's first work assignment for the District was to measure the flow volumes of water, sediment, and nitrate discharging from the springs from the Johnson Island (Block 15) slide area. Subsequent to that project, Mark's major focus has on-farm irrigation as it relates to groundwater recharge and to potential nitrate loading of drinking water sources. A recent District project conducted on behalf of the Columbia Basin Groundwater Management Area (GWMA) involves providing GIS support for mapping the various hydrostratigraphic units within Adams, Franklin, and Grant Counties. Mark also served as the Chairman of the GWMA Hydrogeologic Characterization and Monitoring sub-committee.

- Education: MS, Horticulture, Washington State University

Paul Stoker moved to Othello at the age of nine and helped his father pioneer the family's farm in the new Columbia Basin Project. He helped clear the land to receive the water. After college he returned to farming and has spent the last 32 years as an intensive row crop farmer (potatoes, seed crops, corn, sugar beets, etc.). Mr. Stoker became active in water issues approximately ten years ago. He spearheaded the effort to create a local Groundwater Management Area (GWMA) for Franklin, Grant and Adams counties. He became the Executive Director of the GWMA two years ago.

- Education: Bachelor's degree in Accounting with a minor in Business Management and Economics, Brigham Young University

Robert L. Schuster has more than 250 technical publications on geologic/geotechnical topics, with general emphasis on geologic hazards. His professional field is Engineering Geology and Geotechnical Engineering, with an emphasis on study of geologic hazards, especially landslides. Between 1974 and 1979, he worked for the US Geological Survey; from 1974 to 1979 he was Chief of the Engineering Geology Branch; between 1979 and 1995 he was Research Geologist/Civil Engineer. Since retiring from the US Geological Survey in 1995 he has served as Consulting Engineering Geologist/Geotechnical Engineer; Scientist Emeritus, U.S. Geological Survey.

- Education**:** 1950 – B.S. Geology, Washington State College; 1952 – M.S. Geology, Ohio State University; 1958 – M.S. Civil Engineering, Purdue University; 1960 – Ph.D. Civil Engineering (Geology minor), Purdue University; 1965 – Diploma of. Imperial College, Soil Mechanics, Univ. of London

Kenneth Tiffan is a Research Fisheries Biologist for the U.S.Geological Survey in Cook, Washington where he has worked since 1992. His emphasis has been on juvenile fall chinook salmon life history and rearing habitat requirements primarily in the Hanford Reach and Hells Canyon Reach. Areas of research relating to juvenile fall chinook have included habitat assessment work, investigations of migratory behavior, food habitats and bioenergetics, the effects of high water temperatures, and physiology. He has also been involved in assessing spawning habitat for chum and fall chinook salmon below Bonneville Dam.

- Education: Bachelor of Science and Master of Science, Fishery Biology, Colorado State University, Fort Collins