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David Kaumheimer
Environmental Programs Manager
U.S. Bureau of Reclamation
1917 Marsh Road
Yakima, WA 98901-2058

Fax: (509) 454-5650
Email: storagestudy@pn.usbr.gov

Re: Yakima Storage Study, Draft Planning Report/Environmental Impact Statement

Dear Mr. Kaumheimer:

Thank you for the opportunity to provide comments on the Yakima Storage Study draft DEIS. These comments are submitted on behalf of the Center for Environmental Law & Policy, Columbia Riverkeeper, Citizens for a Clean Columbia (Wenatchee), Rosemere Neighborhood Association, Wahkiakum Friends of the River, Skippers for Clean Water, and Sierra Club.

Our comments are attached.

Yours very truly,

Rachael Paschal Osborn, Executive Director
Center for Environmental Law & Policy

and for:

Columbia Riverkeeper, Brent Foster, Executive Director
Citizens for a Clean Columbia (Wenatchee), Susan Evans, Executive Director
Rosemere Neighborhood Association, Dvija Bertish
Wahkiakum Friends of the River, George Exum, Chair
Skippers for Clean Water, Peter Wilcox, Executive Director
Sierra Club, John Osborn MD, Chair Upper Columbia River Group

Spokane: 509.209.2899 Seattle: 206.547.5047 Olympia 360.754.1520
www.celp.org

Comments on Yakima River Basin Water Storage Feasibility Study, Draft Planning Report/Environmental Impact Statement (January 2008)

Submitted by Center for Environmental Law & Policy, Columbia Riverkeeper, Citizens for a Clean Columbia (Wenatchee), Rosemere Neighborhood Association, Wahkiakum Friends of the River, Skippers for Clean Water, and Sierra Club.

1. Purpose & Need (Section 1.2)

The Bureau of Reclamation's limited review of alternatives to proposals involving dams & reservoirs improperly restricts consideration of other alternatives to satisfy the needs of the project, including non-structural and operational actions that could improve water supply and instream flows. However, the Joint No Action Alternative considers conservation pursuant to sections 1203 and 1204 of Title XII. Moreover, under the SEPA/state alternatives, the term "storage" and the objectives of the study are interpreted in a manner that encompasses a variety of non-structural activities relating to water supply.

It is inappropriate for the Bureau to separate analysis in this study conservation alternatives and other, ongoing studies. Given the critically low water supplies described in the DEIS and quoted above, it is a rather large oversight that conservation is not examined in more detail in the Joint Alternatives. The fact that declared droughts are occurring roughly every five years emphasizes the need for effective conservation measures. Likewise, the "Cle Elum and Bumping Lake Dams Fish Passage Facilities Planning Report," (discussed at Section 1.8.3), scheduled for completion later this year, should be incorporated into this effort. More extensive passage in the Yakima basin will considerably change the nature of water management potential.

2. Storage Study Goals

With respect to the Storage Study Goals (p. 1-3), the DEIS fails to provide information explaining the goal of achieving a 70% proratable supply (896,000 acre feet) for the basin. The goal to make this enormous quantity of water available creates an critical, perhaps unachievable benchmark, and should be thoroughly explained and vetted to determine whether alternative goals are more appropriate. Section 2.2.1.2 is inadequate to explain, other than that irrigation districts assert this is necessary to "avert major economic losses." However there is no discussion of how the term is defined or whether objective evidence indicates this is an appropriate figure. Do Yakima basin pro-ratable irrigators really require 896,000 additional acre-feet of water, and if so, why? The DEIS indicates that Sunnyside and Tieton divisions are not interested in receiving drought water. (Executive Summary, p. xxi). How do these statements affect the goal of 70%?

Likewise, the goal of 82,000 acre-feet for municipal supply admittedly does not include consideration of the potential for water conservation and pricing as a mechanism to control demand. Section 2.2.1.3. Further, there is no discussion of how the acre-feet requirements fit with recent municipal water conservation planning requirements and reasonable efficiency requirements for water rights.

3. Monthly Flow Objectives

In contrast to the out-of-stream water supply goals, the monthly instream flow objectives goal is based on a systematic, technical analysis of instream flow needs and how those needs relate to habitat requirements. We support the development and use of these

objectives. However, we note that objectives for the Naches Arm, an important tributary of the Yakima basin, are missing. The technical process used to establish flow objectives for the DEIS should be utilized to analyze and project similar needs for the Naches subbasin.

4. No Action Alternative

The Bureau should select the No-Action Alternative (as described in Section 2.3) as its preferred alternative for the EIS. However, we note that the use of this alternative as "no-action" is problematic because it may lead readers to the incorrect assumption that the various activities (conservation plan implementation, land and water acquisitions, system improvements) are in fact funded and will in fact occur. (Indeed, the alternative contains a confusing mix of actions that have and have not occurred.) Setting these actions as the "baseline" then undercuts understanding of the substantial improvements in instream flow and water supply that could result if this alternative is actually and fully implemented. Further, failure to conduct a benefit-cost analysis for the "no-action" alternative also limits full understanding by readers and decision makers of the comparative costs of the dam-reservoir alternatives to a conservation-oriented approach.

The No Action alternative is also deficient in its failure to discuss the merits of adjusting basin water demand to actual supply. Water rights in the Yakima were issued according to the exact tenets of the prior appropriation doctrine, that is, over-appropriation to ensure that all water is used during good years, with the assumption that junior water users will plant crops accordingly (ie, not plant perennial crops on lands that may not receive a full supply of water). A large, new storage reservoir would provide an "over-supply" of water to the basin, not needed in many (most) years, and therefore constitute substantial economic waste. Leaving the system as is, i.e., continuing to allow weather and markets to adjust demand, is not adequately explored in the DEIS.

5. Black Rock Alternative

The DEIS discussion of the Black Rock dam-reservoir alternative is inadequate for a number of reasons.

a) Hanford contamination

First, the DEIS fails to provide information about and analyze seepage of groundwater beneath the reservoir and the potential for harm to the cleanup of radioactive and toxic contaminants beneath the Hanford Nuclear Reservation. The DEIS instead defers to a future Department of Energy EIS and states that more information will be provided in the final Yakima Storage study EIS (p. 4-37, 4-71). This is a fatal flaw. The Bureau has the two studies necessary to model and determine impacts (the seepage report and the Hanford groundwater modeling report). The bureau also has the obligation, under NEPA, to address all significant adverse environmental impacts associated with a proposal. Leaving out this discussion frustrates the purposes of NEPA and renders this DEIS inadequate.

Second, even though the DEIS fails to discuss potential adverse impacts to Hanford, it includes discussion of mitigation concepts, presumably to assure readers that we are not to worry about the possibility of harming cleanup at one of (if not THE) most polluted sites in the United States (p. 4-39). This is an improper "cart before horse" approach to discussing impacts.

Third, the costs associated with the Bureau's alleged mitigation schemes for addressing seepage impacts on Hanford are not incorporated into the benefit-cost analysis for the Black Rock alternative (p. 4-39). Again, the DEIS is deficient for its lack of thorough discussion of impacts and costs associated with this critical environmental impact.

b) Geology

The Bureau's discussion of seismic and other geologic issues at the Black Rock site is both inaccurate and inadequate. The DEIS takes the view that any earthquake related hazard, or any other geologic hazard, will be dealt with during dam design and construction. This is not reasonable – it is impossible to engineer the proposed dams to withstand a hazard when the nature and degree of the hazard are unknown. Characterization of the geologic hazards must occur during the Storage Study process. Indeed, the preliminary geologic studies upon which the DEIS is based called for acknowledges that data is sparse and recommends that further studies be conducted. That recommendation has been ignored. The draft EIS is inadequate because it does not address the seismic hazards and other geologic hazards in enough detail to judge the seismic safety of the proposed dams, or to make rational planning decisions.

Attachment 1 to these comments and incorporated by reference are the comments of seismic geologist Harold Magistrale, Ph.D., regarding the seismic and other geologic hazards associated with the Black Rock damsite.

6. Wymer Dam and Wymer Plus Alternative

The Bureau's discussion of seismic and other geologic issues at the Wymer Dam site is both inaccurate and inadequate. The DEIS takes the view that any earthquake related hazard, or any other geologic hazard, will be dealt with during dam design and construction. This is not reasonable – it is impossible to engineer the proposed dams to withstand a hazard when the nature and degree of the hazard are unknown. Characterization of the geologic hazards must occur during the Storage Study process. Indeed, the preliminary geologic studies upon which the DEIS is based called for acknowledges that data is sparse and recommends that further studies be conducted. That recommendation has been ignored. The draft EIS is inadequate because it does not address the seismic and landslide hazards in enough detail to judge the seismic safety of the proposed dams, or to make rational planning decisions.

Attachment 1 to these comments and incorporated by reference are the comments of seismic geologist Harold Magistrale, Ph.D., regarding the seismic and other geologic hazards associated with the Wymer damsite.

7. Cumulative Impacts

In Section 4.2.2.6, the difference between the discussion of the cumulative effects associated with the Columbia River Water Management Program (CRWMP) (one paragraph) and climate change scenarios (13 pages) is striking. Yet we can say CRWMP is likely to affect surface flows in the Columbia River with much greater certainty than we can predict regional future climate (temperature and precipitation changes). The DEIS is deficient for its failure to discuss cumulative impacts associated with various CRWMP projects as they will affect Columbia River flows, including the Lake Roosevelt drawdown, the Potholes Supplemental Feedroute, and the Columbia Mainstem Offchannel dam-reservoir projects (Lower Crab, Sand Hollow and Hawk Creeks). Detailed information is available regarding

each of these projects, including draft and/or final environmental impact statements (SEPA and NEPA driven), appraisal studies, etc. This problem is again repeated in Section 4.4.2.7, which discusses cumulative impacts on hydropower, but fails to discuss the multiple proposed projects that would both require substantial energy resources for pumping, and would remove water from the Columbia River, resulting in net reduction of hydropower production.

The DEIS cumulative impacts analysis fails to identify or address the effects of the proliferation of exempt wells in the already over-appropriated Yakima River Basin. A legislative exemption currently allows unmetered groundwater withdrawals without a permit. Due to the absence of unallocated water in the basin, and the unavailability of water rights for purchase, the legislative exemption has become the rule, rather than the exception, for new residential developments. During 2007 land owners dramatically increased the use of the exemption to support new construction in developments without a water right. Based on 2008 projections, the use of the exemption continues increase at an alarming rate. Unless Ecology quantifies the withdrawals associated with the exemption, and develops mitigation measures to offset future uses, exempt well users may withdraw water in quantities that have a significant impact on surface water flows.

Furthermore, the Growth Management Act mandates that certain counties establish a comprehensive plan and development regulations that protect both the quantity and quality of water resources within the county. The Yakima basin counties affected by this DEIS have failed to comply with this mandate. Continued development without controls and mitigation measures on the use of exempt wells threaten water quality and quantity. Until the Counties have developed comprehensive plans that comply with the GMA, neither Reclamation nor Ecology can project future water demand requirements and impacts.

8. Hydraulic Modeling Omission

The DEIS is inadequate fails to incorporate information and results from the hydraulic modeling (Yakima River Water Management Study, created by Ken Bovee of the U.S. Geological Survey) examining the relationship between flow and habitat parameters that was done as a component of this very study. As noted on the USGS website: "This study will develop an integrated water management/habitat response tool that will allow land managers to quantify the feasibility, effectiveness, and risks associated with various water management alternatives." How the Bureau could issue a DEIS without including the modeling results is entirely unclear.

We would note that CELP asked for but was denied request to extend the deadline for comments and is unable to provide more information about the Water Management Study, which was released less than one week before the DEIS comment deadline.

9. Benefit-Costs

We support the Bureau's NED benefit-costs analysis associated with the joint alternatives (Section 2.7) but wonder to what extent the expenses associated with complicated institutional arrangements (such as described in Section 2.2.5.3, "Effects of Exchange on Yakima River Basin Water Rights") are incorporated into the estimates of costs provided to date. Also, the failure to assess the costs associated with the substantial mitigation scenarios (i.e., to prevent seepage of groundwater to Hanford or replacement of 3,900 acres of shrub-steppe habitat) leaves the reader unable to assess the actual costs

associated with the Black Rock and Wymer alternatives. In this respect the DEIS is inadequate.

We concur in the statements in the DEIS that the Black Rock, Wymer Dam, and Wymer Plus alternatives are "not economically justified." (Section 2.7.1)

Regarding cost of municipal water supply, it is clear that it would be much cheaper to simply purchase water rights for transfer to the cities requiring additional supply to meet future demand. This appears to be the contemplated solution under the "no action alternative," however the DEIS does not make this clear.

Regarding the recreation benefit analysis, the DEIS is deficient for failure to quantify site substitution for use at recreational sites outside the Yakima basin, and instead simply note that the recreation benefits may be overstated (p. 2-85).

We support the Bureau's decision to not include non-use fishery values in the BCA (p. 2-100), given the controversy and difficulty in measuring such values for fisheries in the Yakima basin.

10. Hydrology & Biology

Discussion of hydrology and streamflow issues (from a biological standpoint), occur throughout the document. The DEIS Purpose and Need section states in part:

> "The need for the study is based on the finite existing water supply and limited storage capability of the Yakima River basin. This finite supply and limited storage capability does not meet the water supply demands in all years and results in significant adverse impacts to the Yakima River basin's economy, which is agriculture-based, and to the basin's aquatic resources—specifically those resources supporting anadromous fish. Reclamation and Ecology seek to identify means of increasing water supplies available for purposes of improving anadromous fish habitat and meeting irrigation and future municipal needs."

While true, this statement ignores the fact that the Columbia River is limited by the same phenomena. Two alternatives propose transfer of water from the Columbia to the Yakima. Although this transfer would occur when minimum instream flow requirements for the Columbia are exceeded, this would merely exacerbate one problem to alleviate another.

The DEIS uses target flows established by NOAA Fisheries for the Federal Columbia River Power System's 2004 biological opinion. Not mentioned, is the fact that the 2004 biological opinion was the result of a federal court requirement to revise a 2000 biological opinion that the court deemed inadequate in addressing salmonid recovery. Target flows from the 2004 biological opinion should be considered moving targets in that the 2004 biological opinion has been challenged and remains in court. The DEIS is inadequate for its failure to consider potential changes to Columbia flow targets that may alter water availability for the Black Rock and Wymer Plus alternatives.

The requirements of the Endangered Species Act and the agencies charged with administering it are not adequately addressed in the DEIS. For example, the DEIS includes an attachment, Section IV, which reports and responds to comments of the USFWS, but contains no mention of solicitation of comments on anadromous fish issues from NOAA

Fisheries. In the realm of aquatic resources, status of anadromous fish stocks must receive priority in the Yakima basin. Lack of substantive solicitation of NOAA Fisheries review is magnified by the top priority listed by USFWS, potential loss shrub-steppe habitat.

The "hydrologic indicators" outlined in Tables 2-7 and 2-8 (No Action Alternative), Table 2-26 (Black Rock Alternative), Table 2-37 (Wymer Alternative), Table 2-46 (Wymer Plus Alternative) are presented in units of millions of acre-feet. A much more appropriate indicator of changes to hydrology would be presented in terms of flow. From a biological perspective, changes in velocity throughout the system would also be informative. The volumes presented are more of a commodity than a hydrologic indicator. Likewise, presenting "hydrographs" in terms of volume, rather than flow, makes biological analysis more difficult than necessary. These units for hydrologic indicators are repeated in the State Alternatives analysis (Chapter 5). These indicators might be more accurately termed "Irrigation Adequacy Indicators."

Furthermore, the salmonid species included in the DEIS require certain velocities, in addition to flow, more than simply a volume of water. Ultimately, though, flow objectives for fish should be determined in the absence of irrigation needs and then a compromise sought. Even some of the methods described for flow modeling (Section 4.8.2.1) rely on volumes, rather than flow or velocity.

The hydrograph that is presented (Figures 2.2 – 2.7) definitively shows that none of the alternatives remotely approximates unregulated flow. Comparison of alternatives with mandated target volumes in no way indicates the benefits or detriments of the alternatives to biological communities. However, it is later stated (Section 4.10.2.3) that the Black Rock alternative results in the most "normative/unregulated" flow regime.

Given the severely altered hydrographs in the Yakima, additional withdrawal and storage, as presented in the Wymer alternative, appears to be a poor method by which to increase the health of fish populations. The reasons for the "flip-flop" are described but its effectiveness is not. Alternative flow management regimes should be examined to encourage spawning. The Joint Alternatives sections make several mentions of improvements to water delivery infrastructure including reregulating dams. These are not described but reregulating dams may have substantial positive effects on efforts to re-establish normative flows. Re-regulating dams may also reduce impacts to a variety of systems currently experienced under the flip-flop regime.

The report describes, in some detail, the necessity of unregulated flows for anadromous fish habitat (Section 4.8.1.3) but ignores the responsibility of agencies, and the public in general, to restore these flows and dependent resources. The No Action Alternative results in a number of Title VII target flows being met (Tables 5.6-7). This speaks to the questionable necessity of drastic infrastructure construction. It does not, however, speak to the necessity, to native salmonid recovery, of restoration of normative flows.

The statement that "fisheries habitat conditions have significantly changed through decades of development, both within the Yakima basin and downstream, that preclude achieving near historic anadromous fish populations through actions provided by the Joint Alternatives or any other suite of realistic actions (page 4-118)" is short-sighted and ignores current efforts to accomplish exactly the recovery that Reclamation claims unrealistic. And, indeed, when referencing the Yakima Subbasin Plan, the DEIS describes substantial potential increases in andadromous fish populations.

Ultimately, there is more treatment of fish habitat in the presentation of dismissed alternatives. This, however, amounts to mere mention of impacts to fish habitat. The assumption, in the analysis of Fisheries Benefits, that a fish closed to harvest has "little to no fishery use value" is wholly flawed and inappropriate to an analysis of fisheries impacts. The DEIS mentions that the Yakima is considered a "blue ribbon" trout stream. The fishermen that recognize this often practice catch-and-release fishing, whether harvest is allowed or not.

The Bureau's report on fish habitat (Aquatic Ecosystem Evaluation for the Yakima Basin, USBR, 2008) starkly reports the declines in available anadromous salmonid habitat under the DEIS Alternatives. Loss in available habitat ranges from about 20% decrease to negligible increase, depending on species, life history species, reach and alternative. The unregulated condition routinely results in substantial increases in available habitat, quite often a 20%-40% increase in habitat, depending on species, life history stage, reach and alternative. In the case of subyearling bull trout (a federally listed threatened species) and coho the amount of available habitat nearly doubles in the unregulated condition.

Incidentally, this same report claims substantial increases in "performance" under all alternatives relative to the no action alternative. Performance is "expressed in terms of equilibrium abundance, productivity (maximum adult returns/spawner), carrying capacity and life history diversity (proportion of self-sustaining life history patterns)." These claims contradict other, more conventional metrics, of fish biology which are described in the DEIS.

On page 4-152, the DEIS notes that bull trout typically spawn between September and November. However, the DEIS also makes reference to a study reporting that bull trout spawn between July 15 and September 15. This is a much earlier spawning period than typically applied to bull trout spawning. In the treatment of bull trout in the Affected Environment chapter, this referenced study is not mentioned. Reclamation should be clear about the local biology of this highly sensitive, ESA listed species and the effects of proposed actions on its life history. The Chelan PUD reports bull trout spawning in the Entiat to occur in mid- to late-September (Movement of Bull Trout Within the Mid-Columbia River and Tributaries, 2001-2004, BioAnalysts, Inc., 2004).

The increased flows provided by the Increased Conservation Alternative (Section 5.8) suggest serious examination of this alternative during development of the Final EIS. This alternative has the advantage of a minimal construction footprint compared to the Joint Alternatives. As mentioned above, it is not clear in the DEIS if, and how, Title XII or the 1945 Consent Decree limit the Bureau's ability to pursue the Increased Conservation Alternative jointly.

Washington's newly approved water quality standards apply a period of September 1 to May 15 for Char Spawning and Rearing in the Lower Yakima (WRIA 37), and Naches (WRIA 38) basins (Waters Requiring Supplemental Spawning and Incubation Protection For Salmonid Species, Publication Number 06-10-038, 2006). Char Spawning and Rearing is also a protected designated use in the Upper Yakima (WRIA 39) (Chapter 173-201A-602 (Table 602)). Over the course of several years, considerable professional and public comment went into development of the new water quality standards.

Section 4.6.1.2 states that Washington has no water quality criteria for phosphorus. WAC 173-201A-230 establishes phosphorus criteria for lakes. Some of this language may be applicable to reservoirs in the Yakima basin.

11. Wildlife Impacts

The DEIS does not provide adequate discussion of the value of Black Rock Valley as a wildlife corridor.

12. Anadromous Fish Impacts

The DEIS discussion of impacts on flow and salmon survival should incorporate information from several other studies, including Forward Looking Infrared (FLIR) surveys of surface water temperature, showing hyporheic influence, that have been conducted for the Yakima basin and the Yakima Watershed Salmonid Recovery Strategy, which identifies many of the parameters defined in the DEIS as limiting factors to salmonid recovery (flow, flashiness, sediment, temperature, hyporheic discontinuity). The DEIS includes details about the U.S. Fish and Wildlife Service (FWS) recommendations and the Bureau of Reclamations (BOR) responses. There is no such coverage of any concerns of NOAA Fisheries. An additional such an attachment seems necessary to fully document effects of alternatives on anadromous fish.

13. Recreation Impacts

The recreation impact analysis lacks adequate discussion of the impacts related to Black Rock and Wymer reservoir drawdown. The limited discussion of this important issue and is deficient for failure to include maps (which are available) that indicate exposed lands within the reservoirs that will deter recreational use. The suggestion that drawdown would provide a benefit to ATV and OHV use is absurd (p. 4-178).

There is also tremendous inconsistency in the treatment of this impact and impacts to wildlife and endangered species at the Black Rock site, where mitigation would involve creating corridors to protect what little habitat would be left. (See Section 4.11.2.6).

The DEIS comparison of Black Rock to other, nearby water bodies where there is minimal recreational use, indicates that the projected recreational benefit (based on 250,000 to 700,000 annual visits) is substantially over-stated (annual visits to other reservoirs and rivers in the Yakima basin not equate, in total, to 250,000 annual visits, se Table 4.36, p. 4-175).

14. State Alternatives Generally

SEPA regulations require the Alternatives section of an EIS to "devote sufficiently detailed analysis to each reasonable alternative to permit a comparative evaluation of the alternatives including the proposed action." WAC 197-11-400(5)(c)(v). Chapter 2, the State Alternatives section, fails to provide sufficiently detailed analysis. It is unclear how water savings were determined, how they will be paid for, and how they will be implemented.

CELP generally agrees that water conservation and market alternatives are preferable to expensive (unaffordable) storage proposals. However, the information regarding these alternatives does not meet SEPA requirements and provides an insufficient level of data or analysis to be properly analyzed.

The State Alternatives are also deficient for failure to analyze how water pricing could reduce demand and induce water conservation sufficient to solve water supply and instream flow problems in the Yakima basin. The DEIS should inform readers about the level of subsidy involved in delivery of Yakima basin water to irrigators, and the extent to which a change in pricing structures, imposition of water fees (particularly during drought years) or other similar market-based mechanisms would meet the goals of the study.

15. Enhanced Water Conservation (Section 3.2)

(1) General Comments

The State Alternative, Enhanced Water Conservation (EWC), is vague, unsubstantiated, and/or based on too many assumptions. Alternatives in a SEPA analysis must be sufficiently defined so that the public and agency can base decisions upon informed deliberation. The EWC alternative does not provide the level of detail necessary for the reader to fully appreciate how the alternative offers solutions different than those of the storage alternatives. This lack of sufficient information violates SEPA regulations. WAC 197-11-400(3).

Further, the EWC alternative fails to consider tools already in Ecology's portfolio that could have a dramatic impact on water conservation. These tools are enforcement of illegal water use and metering. The state should analyze the amount of water conservation to be realized through enforcement of existing laws. Moreover, lacking adequate metering data, the amount of conserved water as a result of the enhanced conservation measures will not be accurate. Accuracy of water resource data is important in any basin, but it is vital in the Yakima basin due to over appropriation and the adjudication of the basin. The fact that metering is not included in the study of alternatives speaks to the inadequacy of the overall analysis.

(2) Specific Comments

Section 3.1.2 Summary of Alternative Results

- The summary claims the Enhanced Conservation Alternative will increase instream flows in the Yakima River by 40,000 acre-feet on average and would provide 20,000 acre-feet for proratable water right holders.
    - However, the analysis fails to explain how it determined these figures.
    - The sections that follow discuss the types of conservation projects and compares them to the No Action Alternative, but nowhere in the report is the analysis showing how implementing the Enhanced Conservation Alternative will increase instream flows by 40,000 acre-feet.
- This cursory and insufficient analysis plagues this chapter from start to finish and points out the inefficacy of this document to meet SEPA requirements.

Section 3.2.1 Description

- The Plan states most of the water saved as a result of enhanced water conservation will involve nonconsumptive uses including seepage and return flows. Since only the consumptive portion of a water right can be transferred or reallocated within the Yakima Basin this alternative may actually increase stream depletion in certain reaches. The section notes, "the Yakima Project has some flexibility in its operation and can allow some redistribution of water

within the basin." However, this statement is not further explained and as such it is unclear as to how valuable EWC will be to the overall basin.

Section 3.2.2 Enhanced Water Conservation Projects

- The estimated amount of "conserved" water as a result of the various enhanced conservation projects is presented without any discussion of how these totals were specifically determined.
- The accompanying technical document, *Technical Report on the Enhanced Water Conservation Alternative for the Yakima River Basin Water Storage Feasibility Study*, also does not provide any information on how these savings were calculated.
    - The Technical Report claims the water savings "were determined using information available form water conservation plans and experience of representatives from the local conservation districts."
    - However, no actual data is presented for the public to determine or analyze the assumptions and "experience" of the conservation districts.
    - Therefore, the results of the Enhanced Water Conservation Measures are too vague and unsubstantiated to have any value in a SEPA determination.
- Conserved water can best, and really only, be measured via technically sound metering devices. Source and service meters must be installed in order to correctly determine any water savings as a result of the water conservation projects.

Section 3.2.3 Comparison to the No Action Alternative

- The introduction to the State Alternatives notes, "This chapter describes the alternatives that Ecology is considering under its authority to evaluate both storage and nonstorage alternatives to *improve flows* in the Yakima River basin."
    - However, one option under Section 3.2.3 is to allow all the conserved water to be retained by the implementing entity for use as irrigation or municipal and industrial use.
    - Ecology must explain how this alternative would meet the goal of improving flows in the Yakima River basin.
- If Ecology is going to have an alternative that allows full retention of conserved water by the implementing entity it should also have an alternative that returns all of the saved water to the river for instream flow.
- Ecology assumes at least 67% of the funding for these projects will come from the State, yet the other option still allows for the implementing entity to retain 67% of the conserved water.
    - Since public money is being spent, Ecology should focus on achieving a greater public benefit
    - Another alternative should be included that keeps 67% of the conserved water for instream flow needs and the other third for implementing entity.
- The Enhanced Water Conservation Alternative assumes 67% of its funding will come from the State.
    - This assumption is unsupported by any budgetary analysis. As such it cannot be considered a valid assumption particularly when the State is perhaps facing a future of budget deficits.
    - Ecology offers no alternative to funding these conservation measures.

16. Market Mechanisms (Section 3.3)

As noted above, this proposal should be expanded to include information relating to the of subsidy that is afforded to water recipients in the Yakima basin and consider the efficacy of

regulatory pricing requirements, such as drought-related fees or other mechanisms to reduce water demand and induce water conservation.

As presently written, the information contained in this section is so vague that it is not useful for determining the impacts associated with the proposed actions.

17. Groundwater Storage (Section 3.4)

Although the description of the injection recharge alternative does address the need to insure the quality of the water injected into the aquifers, it fails to discuss the impacts of additional water treatment facilities on the basin as a whole. Active water treatment methods will increase the financial and energy related costs associated with this alternative. Without a quantification of these increased costs, Reclamation and Ecology cannot accurately weigh this alternative against the others.

Both the Surface Recharge with Passive Recovery and the Injection Recharge with Passive and Active Recovery methods discuss Potential Locations. However, the DEIS fails to identify specific locations for municipal aquifer storage and recovery or Surface Recharge with Passive Recovery. Instead the DEIS puts off the determination of locations until the alternative is selected. Without more specific information on the possible storage sites, the effects of this alternative are unquantifiable.

18. Mitigation

The discussion of mitigation requirements contained in Chapters 4 and 5 are vague and too generalized to meet the requirements of SEPA. See, e.g., Sections 4.3.2.6 (groundwater impacts), 4.6.2.6 (water quality); 4.7.2.6 (vegetation and wildlife); 4.8.2.7 (anadromous fish); 4.9.2.7 (resident fish); 4.11.2.6 (threatened and endangered species).

The statement that mitigation is not required for surface water or hydropower impacts does not comport with SEPA, which requires mitigation for all significant adverse environmental impacts. See e.g., 4.2.2.5 (surface water); 4.4.2.6 (hydropower).

Review of the Black Rock and Wymer Dam Sites Geology as Presented in the Draft Planning Report/Environmental Impact Statement Yakima River Basin Water Storage Feasibility Study

Harold Magistrale, Ph.D., J.D.

1. Scope of the review.

This review discusses geologic aspects of the Black Rock and Wymer dam sites as presented in the Draft Planning Report/Environmental Impact Statement Yakima River Basin Water Storage Feasibility Study ('draft EIS') and in the following documents:

- Technical Memorandum No. D-8330-2004-14, *Probabilistic Seismic Hazard Assessment for Appraisal Studies of the Proposed Black Rock Dam* (Reclamation, 2004) ('PSHA study')
- Technical Series No. TS-YSS-5, *Appraisal Assessment of the Geology at a Potential Black Rock Damsite* (Reclamation, 2004) ('Black Rock report').
- Technical Series No. TS-YSS-16, *Yakima River Basin Storage Study Wymer Dam and Reservoir Appraisal Report* (Reclamation, 2007) ('Wymer report').

This review was prepared at the request of the Center for Environmental Law and Policy, an environmental advocacy organization dedicated to the protection of water resources in the Columbia River Basin, and throughout Washington. It was prepared by Harold Magistrale, a California attorney with a Ph.D. in geophysics from the California Institute of Technology, and twenty years of earthquake research experience.

2. Executive Summary

The proposed Black Rock and Wymer dam sites are in the Yakima Fold Belt of east central Washington, a region characterized by folds in the Columbia River basalts. The folds form topographically high ridges that define the impoundment catchments desired for the proposed reservoirs. The folds are formed by earthquake slip on thrust faults (a dipping fault where older rock layers are displaced over younger rocks) within each fold. The Black Rock and Wymer dams, along with appurtenant structures, are to be built on and near these faults. The south abutment of the Black Rock dam is atop a fault. Another fault lies one kilometer west of the Wymer fault. Water conveyance facilities will also cross these faults.

Potential earthquakes on the faults will have effects on the proposed dams:

- Ground shaking. A preliminary study estimates the strength of the shaking at 1 g horizontal acceleration (1 g is the acceleration equal to the Earth's gravitation force). The duration of the potential shaking is unknown.
- Liquefaction. Ground shaking can trigger liquefaction, a type of soil failure that reduces soil strength to zero; this will undermine engineered structures.
- Surface rupture. The displacement of the fault at the ground surface will offset the dam and water conveyance structures.
- Fold growth. The dam abutments are on the folds, and earthquakes are the mechanism by which the folds are formed and grow. During an earthquake, the

entire dam abutment will be deformed and the dam compressed. This effect is not considered in the draft EIS.

- Reservoir induced seismicity ('RIS'). It is commonly observed that the filling of a reservoir can cause earthquakes. The mechanism is thought to be the reservoir head elevating pore pressure and/or lubricating the fault, or the stress perturbation due to the weight of the reservoir. These earthquakes will cause the same effects as natural earthquakes. The draft EIS completely neglects RIS.
- Landslides. The dam sites are prone to landslides because of the steep topography and the presence of weak layers in the bedrock. Earthquake ground shaking can reactivate old landslides, or trigger new ones in currently stable slopes. Also, the impounded water will saturate the slopes surrounding the reservoirs. The saturation can remobilize old landslides and cause new landslides in currently stable slopes.
- A landslide has been tentatively identified at the south abutment of the Wymer dam site, but the draft EIS dismisses its significance on the basis of a cursory inspection. Other existing landslides have been identified upslope from the proposed Black Rock reservoir. A landslide runout into a filled reservoir would displace the impounded water with severe consequences.

Unfortunately, the faults near the dam sites are poorly characterized. The fault slip rates, time between earthquakes, magnitude of potential earthquakes, and the strength and duration of shaking from potential earthquakes are not known. Landslide potential of the slopes around the reservoir sites is scarcely known. The extent and distribution of liquefiable soils is not known.

The preliminary studies (the PSHA study, the Black Rock report, and the Wymer report) recognized the lack of knowledge of the geologic hazards, and all called for further studies to better characterize the hazards. None of those studies has been conducted.

The draft EIS has the view that any earthquake related hazard, or any other geologic hazard, will be dealt with during dam design and construction. This is not reasonable – it is impossible to engineer the proposed dams to withstand a hazard when the nature and degree of the hazard are unknown. Characterization of the geologic hazards must occur during the Storage Study process. The draft EIS is inadequate because it does not address the seismic hazards and other geologic hazards in enough detail to judge the seismic safety of the proposed dams, or to make rational planning decisions.

3. Specific Comments

Section 2.2.2.1 "Black Rock Damsite Seismicity", Paragraphs 1 and 3

The seismic hazard analysis in the draft EIS comes from the PSHA study. The draft EIS claims the PSHA study "documents the preliminary characterization of the earthquake potential at Black Rock dam site." To characterizer the "earthquake potential" would be to characterize the likelihood of timing and magnitude of future earthquakes based on detailed studies of the timing and magnitude of past earthquakes on nearby

faults. Instead, the PSHA study uses sparse existing data to assume a time and space distribution of earthquakes on local and some distant faults, and calculates the likelihood over a period of time of a particular level of ground motion, the peak horizontal acceleration ('PHA') at the dam site. The PSHA study correctly points out that there are only "little or sparse data" to characterize recent earthquake activity (p. 5).

The PSHA results are assumption driven. For example, it is well known that the maximum earthquake a fault is capable of is a function of fault length (Wells and Coppersmith, 1994). The Black Rock Valley fault is under the right (south) abutment of the Black Rock dam. The PSHA study assigns a rupture length of 38 km to the Black Rock Valley fault, with a maximum magnitude of 6.7 (Table 2.2). However, the "Black Rock Valley fault" is actually part of the Rattlesnake Hills structure shown on a recent USGS fault map (see Figure 1), a fault and fold structure with a cumulative length of over 150 km (Lidke *et al*., 2003). The PSHA study treats the Rattlesnake Hills structure as three separate fault segments, each with a certain maximum magnitude controlled by the segment length. However, there is little evidence to characterize the segmentation of the Rattlesnake Hills fault structure (PSHA study, p. 5). If the entire fault structure ruptured, a much larger earthquake would result, with a larger PHA.

The PSHA study emphasizes that it is "an initial Probabilistic Seismic Hazard Assessment … conducted for use in *appraisal-level* studies of the proposed Black Rock Dam." (p. 1) (emphasis added). The PHSA study correctly calls for further study on the age and characteristics of the Black Rock Valley fault under the right abutment of the dam (p. 18). These studies have not been performed. The generalized nature of the PSHA, based on incomplete characterization of the faults at issue, is not adequate. An adequate EIS must include up to date study results of the fault slip rate, average offset, and recurrence interval.

The PSHA study correctly calls for "more complete descriptions of ground motions parameters, including time histories" (p. 18-19). This is in recognition that simple peak amplitudes of ground motion are an inadequate basis for rational engineering and hazard evaluation decisions, and that the duration of the ground motions must be characterized. Such studies are not addressed in the draft EIS. Further, the PSHA study correctly points out that ground motions will be "greatly influenced" by rupture directivity and hanging wall effects (p. 19). Characterization of these factors has not been performed in the draft EIS.

The PSHA study correctly calls for studies of site response (the influence of near surface materials) on earthquake ground motions (p. 19). Site response has long been recognized at having a critical influence on earthquake ground motions (*e.g.*, Milne, 1898). Such studies have not been performed, and are not addressed in the draft EIS.

The PSHA study correctly calls for baseline studies of RIS (p. 19). Such studies have not been performed, and are not addressed in the draft EIS. We address RIS in our comments below.

The calls for more study of the fault are echoed in the 2004 Black Rock report. That report states "The location and geometry of the thrust fault in the right abutment are not well known. Additional investigations are needed to define geometry, slip rates, movement history, and earthquake potential. The investigations will likely require both drilling and trenching" (p. 24). Now, at the time of the draft EIS three and half years later, these necessary studies have not been performed. (Note that in the Black Rock report the fault under the right abutment is called the Horsethief Mountain thrust fault, while in the draft EIS it is called the Black Rock Valley fault.)

The PSHA study properly attempts to include the influence of very large earthquakes in the Cascadia subduction zone on the PHA at the Black Rock dam site. It should be acknowledged, however, that the attenuation functions used in the study (which are based on previously observed ground motions, mostly in California) are likely to be inadequate at the magnitude 8 to 9 range because of the lack of observations of earthquakes of those magnitudes (Youngs *et al.*, 1997).

Section 2.2.2.1 "Black Rock Damsite Seismicity", Paragraph 2

Liquefaction due to earthquake shaking is identified as a concern in the dam materials and foundation area. However, liquefaction is also a concern away from the dam; it has potential effects on ancillary structures such as pipelines, canals, and roadways. Unfortunately, the draft EIS does not identify the extent of potentially liquefiable soils. The EIS should include a detailed soil map with liquefaction potential estimates. This is particularly important because of the anticipated seepage from the reservoir – the seepage may saturate otherwise competent soils downgradient of the reservoir, increasing the liquefaction potential.

Section 2.2.2.1 "Black Rock Damsite Seismicity", Paragraphs 3 and 4

The fold on Horsethief Mountain is associated with the Black Rock Valley thrust fault that surfaces under the south abutment. During an earthquake on the Black Rock Valley fault, the fold grows via northward movement of the rock above the fault (*e.g.*, Suppe, 1985). Thus, during an earthquake, the entire south abutment of the dam will move an unknown amount to the north. (The amount of movement is unknown because the draft EIS has failed to characterize the history of slip per earthquake on the Black Rock Valley fault.) This will cause deformation of the dam with potentially serious consequences. A rational assessment of the dam's response to an earthquake on the Black Rock Valley fault requires an adequate characterization of the past earthquakes on the fault. Such a characterization is absent from the draft EIS.

Section 2.2.2.1 "Black Rock Damsite Seismicity", Paragraph 5

In summary, the draft EIS ignores all the caveats of the preliminary nature of the PSHA study, and the proponents have failed to perform any of the PSHA study's recommendations for additional work to more accurately characterize anticipated strong ground motions from potential future earthquakes. Merely asserting the dams will be designed to handle earthquake ground motions, without sufficient characterization of the causative faults, consideration of the abutment deformation, or extent of potential liquefaction, is inadequate. It is impossible to design and engineer the dams to withstand

earthquakes without an adequate understanding of the nature and degree of the earthquake hazards.

Note that earthquake shaking will affect all appurtenant structures in addition to the dam structures, including water conveyance systems, seepage control systems, service roads, and slope stability (landslides).

Section 2.2.2.2 "Wymer Damsite Seismicity"

No site-specific seismic hazard evaluation was performed for the Wymer dam site. The ground motion considerations are taken from the PSHA study performed for the Black Rock dam site, and much of the discussion in Section 2.2.2.2 was taken from Section 2.2.2.1. We express all the same concerns about the Wymer site as we do for the Black Rock site.

In regards to concerns of fault rupture within the project area, the draft EIS states "Based on the limited preliminary geologic characterization of the site, there is no evidence to indicate that a potentially active fault exists within the dam, dike, or reservoir area." However, "relatively little exploration has been conducted to date, and further investigations could conceivably find evidence of foundation faulting." A rational assessment of the merits of the dam requires more detailed knowledge on the presence of faults in and near the dam site. The draft EIS is inadequate in this respect.

A cursory examination of the USGS fault map (Figure 1) shows that the Umtanum Ridge – Gable Mountain Structure, a 200 km long fault and fold system, runs only a kilometer to the west of the dam site, just across Highway 821 (Lidke *et al*., 2003). The PSHA study included this fault system in its assessment of the Black Rock Valley site PHA. The failure of the draft EIS here to note the proximity of this major fault to the Wymer dam site renders the draft EIS inadequate, and does not build confidence in the seismic hazard evaluation process.

The most common orientation of the faults and folds in the Yakima Fold Belt is east–west, but the Umtanum Ridge – Gable Mountain Structure strikes northwest–southeast near the Wymer dam site (Figure 1; Reidel *et al*., 2003). This part of the fault structure may be associated with the Olympic-Wallowa lineament, an alignment of faults and folds that may represent a fundamental, crustal scale discontinuity (*e.g*., Reidel *et al*., 1994). The different orientation of the Umtanum Ridge – Gable Mountain Structure near the dam site, and its possible association with the Olympic-Wallowa lineament, suggests the fault near the dam site may respond to the regional stress differently than the faults near the Black Rock Valley site (*e.g*., with different recurrence times or different size earthquakes). This suggests that an independent seismotectonic analysis of the Wymer dam site must be performed before the EIS can be considered adequate.

Section 2.2.2.3 "Wymer Dam Potential South Abutment Landslide"

The Wymer report describes the previous identification from air photos of a potential landslide covering the area of the south (left) abutment (p. 7). On the basis of a few hours-long visit to the site (Wymer report, Appendix A), a reconnaissance team decided that the "landslide does not appear to be a deep landslide" (Wymer report, Attachment

2). The rationale for this assessment is not given in either the draft EIS or in the Wymer report. The draft EIS concludes that a "limited amount of geologic investigations at the appraisal stage found no evidence of a large landslide" at the south abutment of the Wymer dam site, but that if one existed then the unstable material would be excavated away.

An air photo of the south abutment (Figure 8 of the Wymer report) exhibits features indicative of a landslide (*e.g.*, Ritter *et al.*, 2002). At the top of the apparent landslide there are arcurate features that appear to be headscarps, and on the slope downhill from those arcurate features the hillside lacks the bedrock outcrops that are common on the slopes just to the east and west. The potential landslide has not been investigated by drilling; only a five feet deep, hand dug pit was excavated (TP-85-1 in the Wymer report).

It would be sensible, from both a cost analysis and geologic hazard determination point of view, to determine during the EIS process whether a landslide exists, and if so, the volume of the material involved. If the feature is a landslide, the excavation costs would be substantial, and the length of the dam would be significantly lengthened to fill in the excavated volume.

Note that landslides that are inactive under current conditions may become mobilized as the material becomes saturated by the impounded water, or may be mobilized by earthquake shaking. These considerations should be analyzed in this section of the draft EIS.

Section 4.3.2.3 "Black Rock Alternative – Long Term Impacts"

The draft EIS correctly points out that landslides are common in the Yakima fold belt (p. 4-37), and that old slides may become reactivated, and new slides form, as seepage from the reservoir infiltrates the surrounding hillsides and increases pore pressure. However, the draft EIS fails to point out that, additionally, old slides may become reactivated, and new slides form, under the influence of earthquake ground shaking.

The Black Rock report identified three large landslides on Horsethief Mountain (p. 21). Two of these landslides have runout zones extending into the proposed reservoir area. If a landslide occurred while the reservoir was full, it would displace water that would overtop the dam and possibly cause structural failure of the dam. For example, in 1963 a large landslide fell into the reservoir behind the Vaiont dam in the Italian Alps, causing a 100 m high wave that overtopped the dam, swept downstream, and killed 2600 people (the dam remained standing). The draft EIS fails to address this issue and so is inadequate.

Because of the concerns of landslides occurring due to seepage and earthquake shaking, and the potential catastrophic effects of a large landslide running into the reservoir, the EIS should contain detailed mapping of landslide potential of the surrounding hills, and a contingency plan to respond to a landslide into the reservoir.

Section 4.3.2.4 "Wymer Alternative – Long Term Impacts"

The draft EIS correctly points out that landslides are common in the Yakima fold belt (p. 4-37), and that old slides may become reactivated, and new slides form, as seepage

from the reservoir infiltrates the surrounding hillsides and increases pore pressure. However, the draft EIS fails to point out that, additionally, old slides may become reactivated, and new slides form, under the influence of earthquake ground shaking.

A potential landslide has been identified under the south abutment, and no convincing evidence has been presented in the draft EIS to contradict that identification. (See discussion of section 2.2.2.3 above.) If a landslide occurred while the reservoir was full, it would displace water that would overtop the dam and possibly cause structural failure of the dam. The draft EIS fails to address this issue and so is inadequate.

Because of the concerns of landslides occurring due to seepage and earthquake shaking, and the potential catastrophic effects of a large landslide running into the reservoir, the EIS should contain detailed mapping of landslide potential of the surrounding hills, and a contingency plan to respond to a landslide into the reservoir.

Section 4.3.2.5 "Wymer Dam Plus Yakima River Pump Exchange Alternative – Long Term Impacts"

We express the same concerns about landslides into the Wymer reservoir. These are not considered in the inadequate draft EIS.

Reservoir Induced Seismicity

Reservoir induced seismicity ('RIS') is the triggering of earthquakes by the physical processes that accompany the filling of reservoirs. As of the mid-nineties there were over sixty well documented cases of RIS from around the world (USGS, 1996), including many earthquakes large enough to cause damage to nearby structures, and in at least two cases – Koyna, India, and Hsinfengkiang, China – the dams came close to failure (Allen, 1982).

RIS earthquakes can occur days to years after reservoir is filled. RIS earthquakes occurring immediately upon filling may be caused by elastic stress changes due to the weight of the impounded reservoir. Seismologists have developed a body of evidence during the last decade that shows earthquakes can be triggered by very small stress changes, on the order of one bar (one bar is about one atmosphere pressure). RIS occurrence after a time delay are likely due to pore water diffusion into the fault zone, driven by the reservoir head. RIS after several years may occur when the reservoir water level is changed; this is thought due to water diffusion plus the elastic stress changes (USGS 1996). Note that seasonally fluctuating water levels are planned for Black Rack and Wymer reservoirs (draft EIS p. 2-40 to 2-41). Deep reservoirs, such as those proposed at the Black Rock and Wymer sites, may be more prone to RIS than shallow reservoirs (USGS 1996).

RIS earthquakes have all the same effects as natural earthquakes discussed above: ground shaking, surface rupture, liquefaction, and landslides. Worldwide observations show that RIS earthquakes occur with a few tens of kilometers of the causative reservoir.

The draft EIS entirely neglects the issue of RIS at all and is therefore inadequate. The draft EIS ignored the recommendation of the PSHA study (p. 19) calling for baseline studies of RIS.

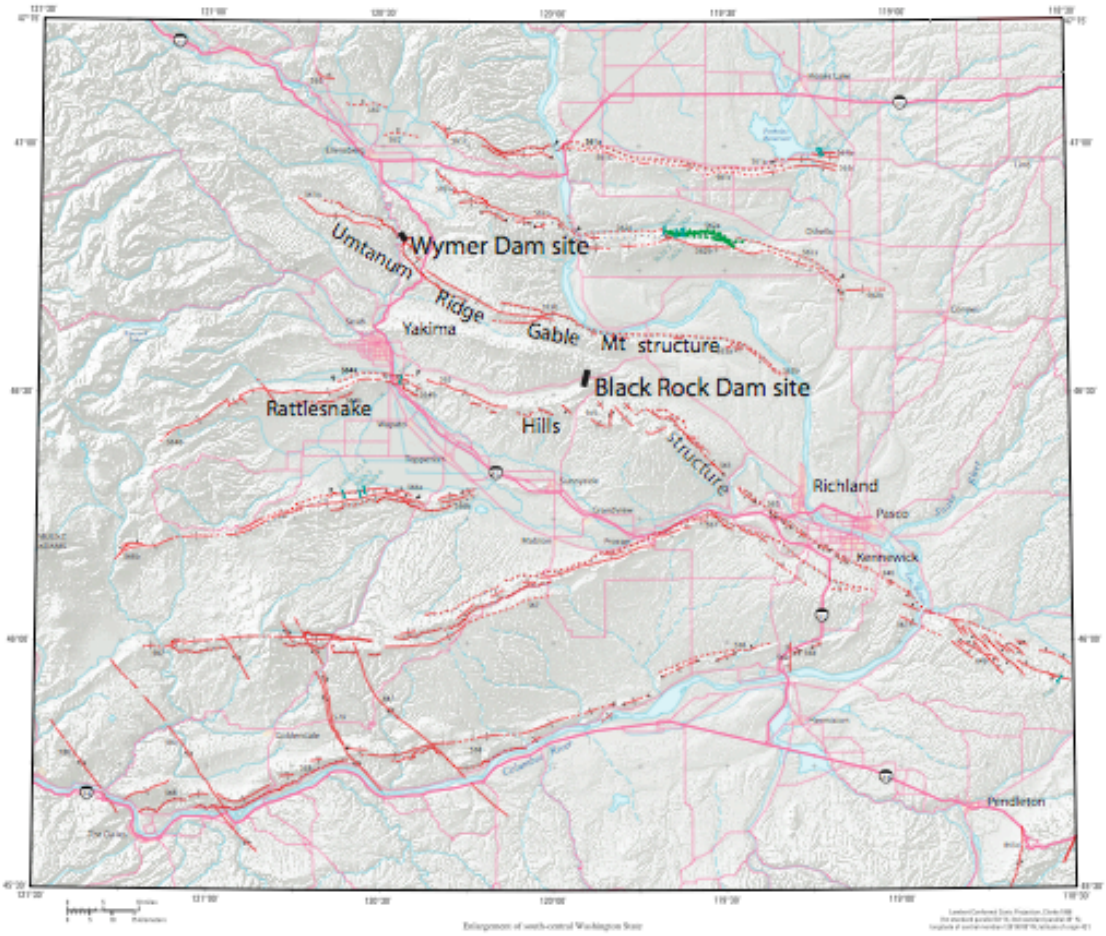

Figure 1. Faults and folds (red lines) in south-central Washington State. Note the proximity of major fault and fold structures to the proposed Black Rock and Wymer dam sites (indicated by black bars). Map is taken from Lidke, *et al.* (2003).

4. References

Allen, C. (1982), Reservoir-induced earthquakes and engineering policy, *California Geology* **35**, 143-147.

Bureau of Reclamation (2004a), *Probabilistic Seismic Hazard Assessment for Appraisal Studies of the Proposed Black Rock Dam*, Technical Memorandum No. D-8330-2004-14.

Bureau of Reclamation (2004b), *Appraisal Assessment of the Geology at a Potential Black Rock Damsite*, Technical Series No. TS-YSS-5.

Bureau of Reclamation (2007), *Yakima River Basin Storage Study Wymer Dam and Reservoir Appraisal Report*, Technical Series No. TS-YSS-16,

Lidke, D., S. Johnson, P. McCrory, S. Personius, A. Nelson, R. Dart, L.-A. Bradley, K. Haller, and M. Machetta (2003), *Map of Quaternary Faults and Folds in Washington State*, U.S.G.S. Open File Report OFR 03-428.

Milne, J. (1898), *Seismology*, 1st ed., London, Kegan Paul, Trench, Truber.

Reidel, S., B. Martin, and H. Petcovic (2003), Structure of the Yakima Fold Belt, central Washington, *in* Swanson, T., ed., *Western Cordillera and Adjacent Areas, Geologic Society of America Field Guide 4*, Boulder, Colorado, p. 277-288.

Reidel, S., N. Campbell, K. Fecht, and K. Lindsey (1994), Late Cenozoic structure and stratigraphy of south-central Washington, *in* Lasmanis, R., and Cheney, E., eds., *Regional geology of Washington State*, Washington Division of Geology and Earth Resources, p. 159-180.

Ritter D., R. Kochel, and J. Miller (2002), *Process Geomorphology*, 4th Edition. McGraw Hill, New York.

Suppe, J. (1985), *Principles of Structural Geology*, Prentice-Hall Inc., Englewood Cliffs, New Jersey, 537 pp.

USGS Auburn Project Review Team (1996), *Review of seismic-hazard issues associated with the Auburn Dam project, Sierra Nevada foothills, California*, U.S.G.S. Open File Report 96-0011.

Wells, D. and K. Coppersmith (1994), New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement, *Seismological Society of America Bulletin* **84**, 974-1002.

Youngs, R., S.-J. Chiou, W. Silva, and J. Humphrey (1997), Strong ground motion attenuation relationships for subduction zone earthquakes, *Seismological Research Letters* **68**, 58-74.