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

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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

<u>Section 2.2.2.1 “Black Rock Damsite Seismicity”, Paragraphs 1 and 3</u>

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.

<u>Section 2.2.2.3 "Wymer Dam Potential South Abutment Landslide"</u>

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.

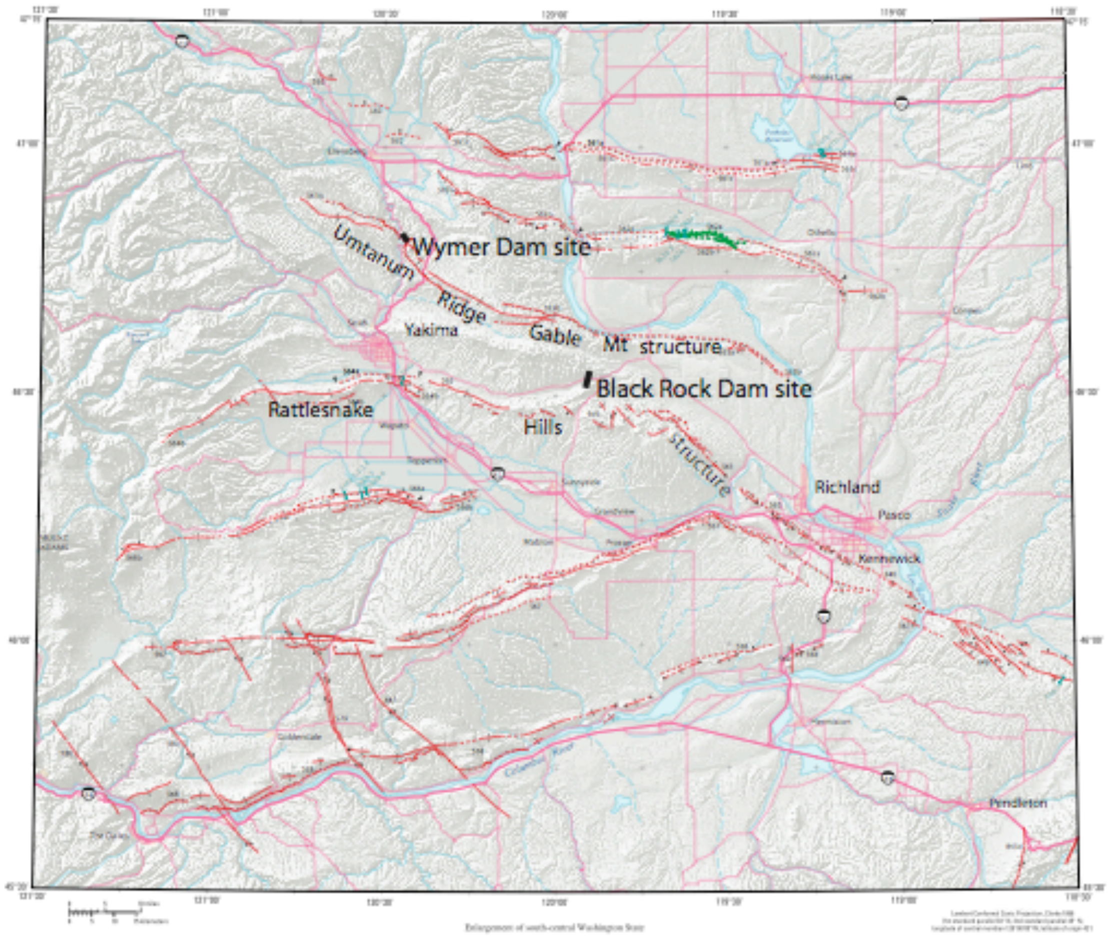

Figure 1. Faults and folds (red lines) in south-central Washington State. Note the proximity of major fault and fold structures to the proposed Black Rock and Wymer dam sites (indicated by black bars). Map is taken from Lidke, *et al.* (2003).

4. References

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