Appendix F: Comment Letter from Dr. Timothy Stark

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Dr. Gerald Bowes
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RE: External Peer Review of Sediment Total Maximum Daily Load (TMDL) for the Upper Elk River Reports and Rationale

Dear Dr. Bowes:

Pursuant to your request, I have reviewed the documents listed below in support of the proposed Sediment Total Maximum Daily Load (TMDL) for the Upper Elk River. The documents reviewed are:

- Staff Report to Support the Technical Sediment Total Maximum Daily Load (TMDL) for the Upper Elk River including various appendices (State of California, March, 2013)
- Summary of TMDL Summary and Implementation Framework and Basin Plan
- Draft Amendment of Beneficial Uses in Elk River
- Description of Assertions, Findings, and Conclusions to be Addressed by Peer reviewers

This report presents my external and unbiased review comments of the proposed Sediment Total Maximum Daily Load (TMDL) for the Upper Elk River to assess and control sediment discharges in the Elk River in an effort to restore and protect water quality in the Elk River Watershed. The Upper Elk River is experiencing excessive sediment discharges from the Upper Elk River subbasin, primarily due to the effects of industrial timber harvesting.

I reviewed the above documentation and my comments are focused on the scientific issues that are relevant to the proposed "*TMDL Summary and Implementation Framework and Beneficial Uses Amendment*". Given the current status of the Upper Elk River, my comments favor action over no action instead of requiring additional study and/or data. In particular, I focused on whether or not the slope stability analyses and assessments are based upon sound scientific knowledge, methods, and practices. I also commented on some other aspects of the proposed action even though the Regional Water Boards will have to respond to my comments to ensure a successful plan is implemented and result is achieved.

FOCUS OF PEER REVIEW:

Pursuant to David Jenkins' 24 August 2012 request, my peer review focused on slope stability issues but I have reviewed all of the documents listed above. Some of the slope stability issues that I considered during my peer review include:

- landslide processes,
- slope stability modeling and input parameters
- slope stability analyses, e.g., deterministic and probabilistic
- landslide hazard mapping
- risk assessments

In accordance with Dr. Jenkins' 24 August 2012 request, I focused on the following three specific slope stability issues:

1. Is the 4-meter **Digital Elevation Model** (DEM) generated from the bare-earth Light Detection and Ranging (LiDAR) points using kriging a reasonable technique to model hillslope stability in the project area to maximize representative elevations and definition of actual geomorphic features while reducing topographic artifacts and computation time required for model application and other spatial analyses?

2. Do **SHALSTAB and PISA** represent reasonable models for predicting potential shallow landslide hazards, in common usage with proven performance in forest mountainous terrain?

3. Does the model testing that resulted in determination of **Appropriate Thresholds for breaks in potential instability classes** balance the goals of maximizing correct landslide prediction and minimizing over prediction of unstable area?

To address these three issues, my review focused on the following documents:

- Sections 4.3, 4.4, and 5.2 of Staff Report to Support the Technical Sediment Total Maximum Daily Load (TMDL) for the Upper Elk River including various appendices (State of California, 2013)
- Appendix 2B - "*LiDAR Campaign, Freshwater Creek Watershed and Elk River Watershed Tributaries of Humboldt Bay, California*" prepared by Sanborn in Colorado Springs, Colorado, March, 2005.
- Appendix 4E - "*Freshwater Creek Watershed and Elk River Watershed Tributaries of Humbolt Bay, California*" prepared by Pacific Watershed Associated in Arcata, California, August, 2006.

- Appendix 4F - "*Management-Related Shallow Landslide by Ownership*" prepared by State of California, March, 2013.
- Appendix 6D - "*Landslide Hazard in the Elk River Basin, Humboldt County, California*" prepared by Stillwater Sciences in Arcata, California, June, 2007.

Below I present my general review comments to these three specific slope stability issues, then present some detailed review comments on these five slope stability related documents in Appendix A. Given the current status of the Upper Elk River, my general review comments favor action over no action. However, my detailed review comments are intended for use if additional studies are performed to improve the current slope stability analyses. These detailed review comments provide suggestions for different input parameters, analyses, and design criteria for predicting future slope instability and thus river sediment. As a result, it is not necessary for the Regional Water Boards to respond to my detailed comments in Appendix A but to acknowledge that they will be considered in future studies and analyses.

BACKGROUND ON ELK RIVER WATERSHED:

Elk River is a 58.2 square mile watershed located in the coastal temperate rain forest of Humboldt County in northern California, which enters Humboldt Bay just south of the City of Eureka (State, 2013). In 1998, the entire Elk River watershed was identified as impaired due to excessive sedimentation and placed on the Impaired Waters List as required under section 303(d) of the Clean Water Act (State, 2013). Humboldt Bay is an important economic resource, which supports shipping, boating, recreation, and fishing activities.

The North Coast Regional Water Quality Control Board (Regional Water Board) divided the watershed into the following three waterbodies (State, 2013): Upper Elk River (44.2 sq. mi.), Lower Elk River (14.3 sq. mi.), and Upper Little South Fork Elk River (3.6 sq. mi.). The Regional Water Board proposes the impairments in the Lower Elk River be addressed via regulatory programs that will address stormwater flows from the City of Eureka and runoff from agricultural lands. The Upper Little South Fork Elk River currently achieves water quality standards and beneficial use protection so it is recommended for delisting from the Impaired Waters List. As a result, the focus of this peer review is only the Upper Elk River.

ELK RIVER WATERSHED WATER QUALITY:

The Elk River was first included on California's 303(d) impaired waters list in 1998 because of excessive sedimentation/siltation. The excessive sediment has impaired beneficial uses of the water, including fisheries habitat, domestic and agricultural water supplies, recreation uses, flood peak attenuation and water quality enhancement functions. The Upper Elk River Watershed is tectonically-active, steep, unstable, and underlain by weak geologic formations that weather to fine grained silts and sands. Extensive timber harvesting has accelerated sediment production from the naturally erodible landscape and contributed to the sediment that is impairing the Elk River.

Extensive re-entry harvesting and road construction activities began in 1986 and were followed by large winter storm events that augmented erosion. Large discharges of sediment and organic debris resulted in morphologic changes to the channel and floodplain in the middle reach of the Elk River watershed, significantly impairing domestic and agricultural water supplies and coldwater fisheries habitat and causing an increase in flood frequency and magnitude.

SLOPE INSTABILITY AND INCREASED SEDIMENTATION:

The Upper Elk River subbasin is underlain by erodible and weak geologic formations. Unfortunately the steepness of the slopes in this subbasin combined with the geologic formations and rainfall produce unstable slopes. In addition, the natural vegetative cover of the redwood forest helps stabilize the steep slopes with a canopy that intercepts rainfall and acts as storage for water through evapotranspiration instead of infiltrating the soil and decreasing stability. As a result, removal of trees and their canopy causes increased infiltration and potential slope instability. The watershed has supported commercial timber operations since the late 1800s but intensive clear-cut logging beginning in 1986, and followed in the 1990s with years of larger-than-average rainfall, have resulted in widespread landsliding and erosion.

THREE SPECIFIC SLOPE STABILTIY ISSUES:

1. 4-meter Digital Elevation Model (DEM)

This section presents my review of the 4-meter Digital Elevation Model (DEM) generated from the bare-earth Light Detection and Ranging (LiDAR) points using kriging as a reasonable technique to model hillslope stability in the project area to maximize representative elevations and definition of actual geomorphic features while reducing topographic artifacts and computation time required for model application and other spatial analyses.

One of my recent doctoral students, Kamran Akhtar (Akhtar, 2011), used DEMs and kriging to develop three-dimensional (3D) slope geometries from topographic data for input to a new 3D limit equilibrium slope stability model. As a result, I am familiar with generating DEMs from LiDAR and the kriging method. In March of 2005, Sanborn (2005) was contracted by Space Imaging to perform a LiDAR survey in the Humboldt Bay Area in Northern California. LiDAR data in the form of 3D positions of a dense set of masspoints was used to develop a DEM of the area.

Based on my experience and the reports prepared by Sanborn (2005) and Pacific Watershed (2006), it is my opinion that the use of LiDAR to develop DEMs using kriging is based upon sound scientific knowledge, methods, and practices. Thus, the use of DEMs and kriging is a reasonable technique for modeling hillslope geometry to capture representative elevations and geomorphic features for the slope stability analyses discussed below. The DEMs models described above were used as input for the slope stability analyses performed using SHALSTAB and PISA to predict areas of stability and potential instability.

2. SHALSTAB and PISA

This section presents my review of the limit equilibrium slope stability models SHALSTAB and PISA and whether or not they are reasonable models for predicting potential shallow landslide hazards, in common usage with proven performance in forest mountainous terrain, and are reasonable to estimate hillslope instability in an effort to predict Elk River sediment potential.

Both SHALSTAB and PISA are commonly used to predict potential shallow landslide hazards in forested mountainous terrain and are relevant to other slope applications, such as dam and levee slopes and landfill final cover systems, because they are based on the infinite slope model. SHALSTAB and PISA are deterministic (Dietrich et al. 2001) and probabilistic (Haneberg 2004, 2005), respectively, slope stability models.

The infinite slope method is the simplest stability method because the many assumptions result in the slope being modeled as a block on an incline. The analysis assumes the slope extends infinitely in all directions and sliding occurs along a plane parallel the slope face. Because the slope is infinite, the stresses along planes A-A' and B-B' in Figure 1 are the same and cancel each other. This results in a simple expression to calculate factor of safety. Other major assumptions in the method include:

- Potential failure surfaces are parallel to the ground surface which is dubious in mountainous terrain,
- Shallow subsurface flow is parallel to the ground surface which is dubious because of the variability of infiltration
- Soil properties, e.g., unit weight and shear strength, above the planar failure surface are assumed to be homogenous or constant, which may not be the case in mountainous terrain
- The factor of safety is constant along the failure surface, which may not be appropriate
- Slope angle is constant, which is dubious in mountainous terrain,
- Depth of soil is small compared to the lateral dimensions of the slope so 3D effects are not significant.
- Root strength is neglected.
- Peak strength values are used to model the slope soil.

- Resisting forces at the downslope end of the block are ignored, which is conservative especially if tree roots are present.

The infinite slope method is more appropriate for cohesionless soils but can also be used for cohesive soils. The assumptions above usually result in a conservative estimate of factor of safety which means that some areas that are predicted to be stable may not be and will contribute to the sediment load. The results of the stability analyses were compared with Upper Elk River landslide inventories so the analyses appear reasonable.

In summary, SHALSTAB and PISA represent reasonable models for predicting potential shallow landslide hazards in forest mountainous terrain and are in common usage with proven performance in this application. However, some detailed comments are presented below for improving the analyses if future analyses are performed, such as using a more rigorous slope stability analysis than an infinite slope analysis, stress dependent shear strength, and partially saturated soil behavior.

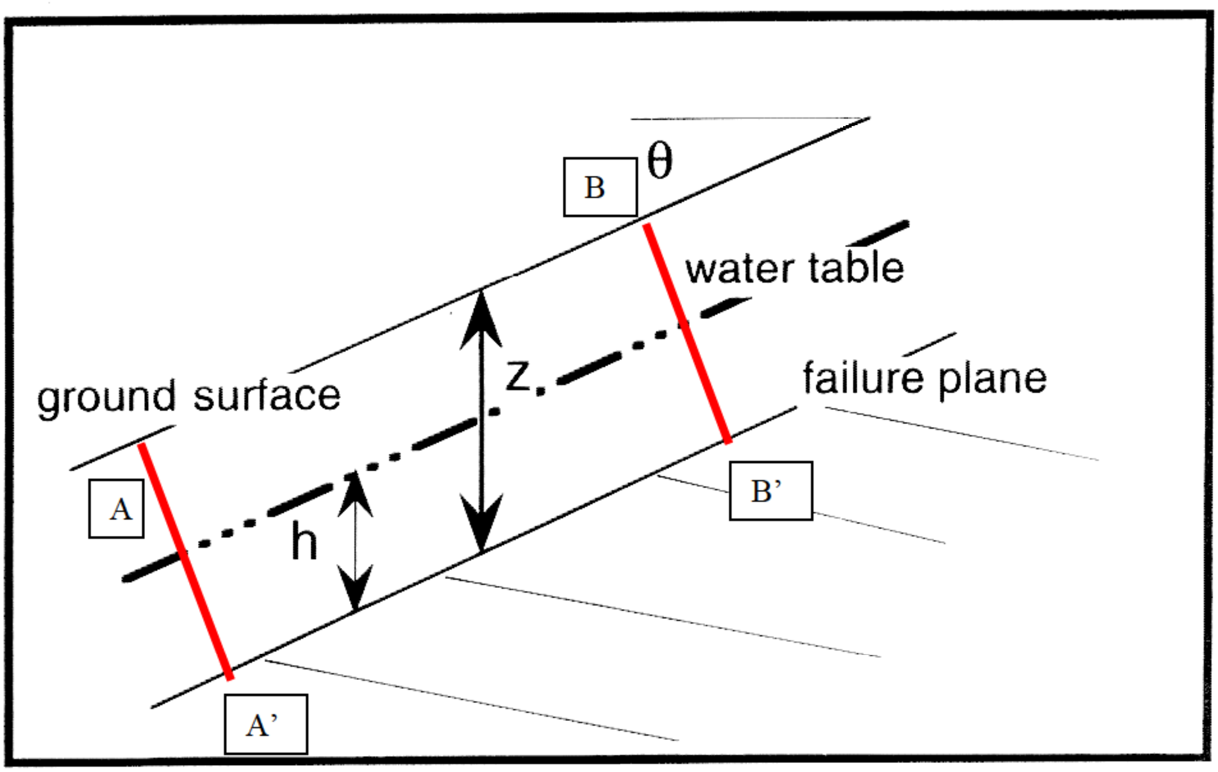

Figure 1. Infinite slope stability model showing parallel failure plane, water depth of "h", slope angle of θ, and ground surface with colluvium thickness of "z" (figure from Dietrich and Montgomery, 1998)

3. Instability Class Thresholds

This section presents my review of the thresholds for determining the instability classes presented in Stillwater Sciences (2007) to determine if the thresholds balance the goals of maximizing correct landslide prediction and minimizing over-prediction of unstable area. This is important because timber harvest operations should probably not be allowed in areas of high landslide hazard.

Some of the key factors contributing to slope instability are listed below so the instability thresholds should reflect at least some of these factors:

- slope gradient,
- soil thickness especially for cohesive slopes,
- canopy because it reduces infiltration,
- rainfall,
- soil strength, pore-water pressure, and unit weight, and
- geologic formation.

Stillwater Sciences (2007) uses four slope models to predict potential shallow landslide hazards in the Elk River basin. Two of the models are deterministic and based on SHALSTAB, i.e., SHALSTAB and SHALSTAB.V while the other two models are probabilistic and are PISA and PISA.V. SHALSTAB.V is similar to SHALSTAB but includes more parameters to describe spatial variability in soil depth. PISA.V is a second version of PISA that uses a 4-m grid of variable soil depths as used in SHALSTAB.V but includes probabilistic analyses. All other parameters and probability distributions used for PISA.V are identical to that described for PISA.

SHALSTAB uses values of log(q/T) to delineate areas of slope instability. Specifically, high, moderately high, and moderate potential instability are represented by areas where log(q/T) is less than or equal to -3.1, -2.8, and -2.5, respectively. These preliminary classes are based on suggested log(q/T) thresholds reported for SHALSTAB applications in other areas (Dietrich et al 2001, Montgomery et al. 1998). The pattern of potential instability predicted by SHASTAB and SHALSTAB.V is similar, where areas with relatively high potential for shallow instability generally occur on steep convergent slopes.

SHALSTAB is an infinite slope stability model with a steady-state hydrologic model so the following coupled hydrologic-slope stability equation is used to calculate the factor of safety:

$$\frac{q}{T} = \frac{\rho_s}{\rho_w} * \left(1 - \frac{\tan\theta}{\tan\phi'}\right) * \frac{b}{A} * \sin\theta$$

where:

$\sin\theta$ = hydraulic head gradient, dimensionless
θ = slope angle, degrees
ϕ' = effective stress angle of internal friction of soil mass along failure plane, degrees
ρ_s = soil bulk density, mass/volume
ρ_w = water bulk density, mass/volume
q = effective precipitation, volume
T = downslope transmissivity which is related to saturated hydraulic conductivity
A = drainage area
b = width of outflow boundary.

Inspection of this equation shows the hydrologic ratio, q/T, captures the magnitude of effective precipitation (represented by q) relative to the subsurface downslope transmissivity (represented by T). The larger the ratio of q/T, the greater the likelihood that the ground will saturate and be more prone to slope instability. The topographic ratio b/A*sinθ describes the effects of convergent topography on concentrating runoff and elevating soil pore water pressure, which effectively reduces soil shear strength.

This brief background shows that using values of q/T to delineate areas of different slope instability is reasonable and represents a sound scientific approach or method because of the large impact that precipitation and transport of the precipitation have on slope stability.

PISA and PISA.V also utilize an infinite slope stability model with probabilistic features so the spatial distribution and magnitude of probability of failure can be calculated and are shown in Figures 3-3 and Figure 3-4, respectively, of Stillwater Sciences (2007). Values of probability of failure are a common output of probabilistic slope stability analyses and are commonly used to delineate ranges of potential instability. Therefore, using values of probability of failure to delineate areas of different slope instability is reasonable and represents a sound scientific approach or method.

In summary, the use of q/T and probabilities of failure are suitable and logical parameters to delineate areas of potential shallow landsliding in forest mountainous terrain. However, some detailed comments are presented below for improving the analyses if future analyses are performed, such as using a p-test value lower than 0.5 (for example, $p<0.3$) and different sampling criteria to assess the accuracy of the probabilistic stability analysis.

SUMMARY:

The Elk River watershed has supported commercial timber operations since the late 1800s but intensive clear-cut logging beginning in 1986, followed in the 1990s with years of larger-than-average rainfall, have resulted in widespread landsliding, erosion, and river sedimentation. I reviewed the above documentation and it is my opinion that the slope stability analyses and assessments are based upon sound scientific knowledge, methods, and practices. In short, the use of:

- 4-meter **Digital Elevation Models** from bare-earth Light Detection and Ranging (LiDAR) points using kriging is a reasonable technique to model hillslope geometry in stability analyses.

- **SHALSTAB and PISA** represent reasonable models for predicting potential shallow landslide hazards and are in common usage in forest mountainous terrain.

- The stability models resulted in reasonable classes of slope instability that balance the goals of maximizing correct landslide prediction and minimizing over-prediction of unstable area. This is accomplished using values of q/T for the SHALSTAB analyses and probabilities of failure for the PISA analyses.

If you have any questions about my peer review comments or if I can provide any additional information, please contact me using the contact information shown above.

Sincerely yours,

Timothy D. Stark, Ph.D., P.E., F.ASCE, D.GE

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Stillwater Sciences (2007). "Landslide Hazard in the Elk River Basin, Humboldt County, California: Final Report," Prepared by Stillwater Sciences, Arcata, California for North Coast Regional Water Quality Control Board, 5550 Skylane Boulevard, Suite A, Santa Rosa, California 95403, June 1, 153 p.

APPENDIX A – Specific Comments on Various Reports

Specific Comments on Various Reports

This appendix presents some specific review comments on the Pacific Watershed (2006), Stillwater Sciences (Stillwater, 2007), and Staff (State, 2013) reports. My approach to this review is to favor action over no action because of the current status of the Upper Elk River. As a result, many/most of these specific comments should be considered to be suggestions for future improvement and research to identify the locations of potential instability and more importantly to estimate the potential Elk River sediment load under different natural and management scenarios.

Review of Appendix 4E - Pacific Watershed (2006):

This section presents my review comments on the report in Appendix 4-E of (State, 2013) titled: "*Landslide Hazard in the Elk River Basin, Humboldt County, California*" prepared by Stillwater Sciences in Arcata, California.

- **Section F – Discussion and Conclusions:**

As discussed below, there should be a strong correlation between the three forest age classes presented in this report and landslide sediment production and delivery that could be included in the stability analyses to relate slope instability to Elk River sediment load. Table 19 of this report shows the sediment load from each forest class and each forest class canopy is used to develop a canopy coverage coefficient. Therefore, changes in canopy coverage can be related to potential slope instability and Elk River sediment load which could be used to select areas for limiting timber harvesting.

For example, it appears increasing sediment delivery is derived from younger harvest ages which may suggest reducing timber harvesting in these areas versus older harvest ages (see Table 19 of this report). This could also be reflected in the stability analyses by using different shear strength parameters for young and older harvest areas.

Finally, management practices can influence slope stability so including typical management practices in the stability analyses via input parameters such as infiltration, soil shear strength, slope gradient, etc., may be beneficial for better landslide hazard mapping. This could be accomplished by creating different categories of landslide causation mechanisms for small landslides to correlate management practice and landslide volume or sediment production.

Review of Appendix 6D - Stillwater Sciences (2007):

This section presents some detailed comments on the report in Appendix 6-D of (State, 2013) titled: "*Landslide Hazard in the Elk River Basin, Humboldt County, California*" prepared by Stillwater Sciences in Arcata, California for improving the analyses if future analyses are performed.

- **Section 1 - Introduction:**

When considering landslide hazard assessment it is important to recognize that landslides usually do not reoccur in the same location because the prior movement has reduced the driving stresses so areas of no prior sliding and thick colluvium should be emphasized to predict areas of future landsliding.

- **Section 1.2.4 – Sediment Sources:**

The majority of sediment delivered to the North Fork Elk River system originates from landslides so using Best Management Practices, e.g., geowebs in road construction, may reduce landsliding and sediment generation.

- **Section 2.1 – Geomorphic Terrains:**

Currently four main attributes are being used to define geomorphic terrains in the Elk River Project Area based on their role in regulating erosion and transport processes: geology, hillslope gradient, channel gradient, and vegetation cover type. It is recommended that colluvium depth and change in canopy cover be included. For example, Figure 1-3 includes canopy removal coefficients that could be included in generating landslide hazard maps.

- **Section 2.3.2.1 – SHALSTAB:**

The following are some suggestions for refining the input parameters used in the SHALSTAB analyses:

1. Do not increase effective stress friction angle, ϕ', to reflect root strength because soil will be saturated and possible near the liquid limit

2. Do not use peak strength, i.e., peak friction angle, peak ϕ', for colluvium because prior downslope movement of colluvium usually results in mobilizing a post-peak strength, e.g., residual friction angle.

3. Include partially saturated seepage in stability analyses instead of using saturated hydraulic conductivity

- **Section 2.3.2.2 – SHALSTAB.V:**

Soil thickness strongly influences slope stability and determining how much soil is involved in the slide mass. Future analyses should include modeling the partially saturated nature of the colluvium to better predict depths and magnitude of infiltration. In addition, field observations should measure colluvium depths so isopach maps can be generated because LiDAR does not provide an estimate of soil depth. This can be facilitated using handheld probes that can be quickly inserted into the colluvium to measure depth, e.g., http://www.grainger.com/Grainger/DICKEYJOHN-Soil-Compaction-Tester-2LBB3 or http://www.southernstates.com/catalog/p-3377-stainless-steel-deepcore-probe-soil-sampler-36.aspx.

- **Section 2.3.3 – Deep-Seated Landslide Models:**

I think the physical factors controlling deep-seated mass movement are well understood, i.e., not poorly understood as reported, and many physical models, e.g., SLOPE/W and SLIDE, are available to assess deep-seated landslide hazards. However, deep-seated slides are not a sensitive to short rainfall events because of the time required to infiltrate the larger slide mass. If field data indicates a large number of deep-seated slides, a more rigorous model could be implemented.

- **Section 2.4.1 - Hypothesis Testing:**

As mentioned above, the p-test value should be varied and different sampling criteria used to assess the accuracy of the probabilistic stability analysis. The following discusses the importance of using different p-test values and sampling criteria on the hypothesis testing.

- **Section 2.4.1.1 - Hypothesis Testing:**
    - Using different p-test values (e.g., $P < 0.4$, $P < 0.3$, etc.) would yield a higher confidence of the instability prediction of a random point being lower than a known landslide point.
    - What is the % area (relative to the gross area) of landslides? When selecting random points, are landslide points selected randomly too? The % area of landslide locations will affect the p-test value because instability of a random point is more likely to be greater than the computed instability at a known landslide point compared to other randomly selected points.
        - For example (assume random points can be selected anywhere in the site): if Z_i is selected randomly at a known landslide location (selected luckily) and Z_j is instability of a known landslide location (selected intentionally), the chance of $Z_i \geq Z_j$ is higher. Thus, the p-test value is affected by the % known landslide area because the greater the % area of known landslides the greater the chance of selecting a known landslide location during the random selection (Z_i). Therefore, the null hypothesis can be rejected

incorrectly (because p-value > 0.5) when the % of known landslide area is high.
- In summary, it is important to know/show the landslide information and how they sample the landslide points to obtain the p-test value. This is needed to better understand the validation process.

- **Section 2.4.1.3 – Potential Instability Thresholds**
  - Is there any evidence to support the assumption A = B in this cost analysis?

- **Section 3.2.1 - Model performance based on p-tests**
  - Does $P > 0.5$ or $P \leq 0.5$ provide enough evidence to determine whether or not the model is performing well? Is there any evidence besides $P > 0.5$ to validate the conclusion that the model is performing well?

- **Tables 3-2 through 3-4**
  - These tables are simply confusing, see below. The information provided does not show a clear objective/conclusion. For example, knowing 32% of the time SHALSTAB.V is performing better than another model and 33% worse by comparing p-test values does not seem convincing.

- **Table 3-5**
  - What does cumulative area mean? Is it the landslide area? Total area? Please provide additional detail on the area terms?

- **Figures 3-3 and 3-4 – PISA v. PISA.V**
  - These two figures use a range of probability of failure of 2 % to 100%. Figure 3-3 indicates there are considerable areas of potential slope instability but Figure 3-4 shows there is little area of potential instability. Thus, Figure 3-4 could be used to infer that timber harvesting could occur throughout the area. A detailed explanation of the difference in these two figures should be discussed and recommendations for timber harvesting presented.

- **Figures 3-1 and 3-2 – SHALSTAB v. SHALSTAB.V**
  - These two figures use a range of q/T to indicate areas of potential slope instability. There is much closer agreement between these two analyses than observed for the PISA and PISA.V analyses in Figures 3-3 and 3-4. A detailed

explanation of the difference between Figures 3-1 and 3-3 and Figures 3-2 and 3-4 should be presented because the comparison in Tables 3-2 through 3-5 is confusing at best. Table 3-5 is really difficult to comprehend.

- **Section 4.1 – Uses and Limitations:**

The landslide hazard mapping presented does not directly address potential sediment delivery from landslide-prone areas to the Elk River. As mentioned above, one missing parameter is measurements of soil thickness throughout the area. This may be able to be facilitated with some handheld probes that can be quickly inserted into the colluvium to measure depth, e.g., http://www.grainger.com/Grainger/DICKEYJOHN-Soil-Compaction-Tester-2LBB3 or http://www.southernstates.com/catalog/p-3377-stainless-steel-deepcore-probe-soil-sampler-36.aspx.