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Hydrology and Earth System Sciences Discussions

# *Interactive comment on* "The cumulative effects of forest disturbance on streamflow in a large watershed in the central interior of British Columbia, Canada" *by* M. Zhang and X. Wei

**M. Zhang and X. Wei**

adam.wei@ubc.ca

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General Comment The article is an interesting and informative piece of work that will be of interest to your readers and will help improve watershed management activities. The authors have done well to provide the material in such a short format. I have annotated the document to highlight i) text errors, ii) terms/phrases that may need to be deleted and I have also provided direct comments and questions that should be addressed prior to article publication. I believe the figures can be improved, including more descriptive axis labels as well as being re-sized and darkened to ease reader



review. Figure 1 should be improved including provision of scale(s), correct dimension for the province, and perhaps more detail at the watershed level to identify locations mentioned in the text. For those readers unfamiliar with ECA, it would be helpful to provide more detail on its calculation.

Authors' responses: We have corrected editorial errors and revised the text and figures according to the reviewer 2's suggestions. Please see our responses to those specific comments. Thanks for your constructive suggestions and great efforts in reviewing this paper.

Specific comments

1. 2856/06: What was the pine content of the watershed? 30-50-70-etc.?

Authors' responses: We provided the pine content information in the text. "85% of forest stands are pine-leading and 83% of them have been attacked by MPB. Up to 2009, forests attacked by MPB came up to 70.2% of the total watershed area…"

2. 2857/24: not sure it is widely used in Canada, BC an Alta- certainly

Authors' responses: We revised our statement. " an indicator widely used in British Columbia and Alberta"

3. 2857/26 perhaps provide examples... i.e. harvest blocks, agricultural areas, residential development, roads and right-of-ways, etc.

Authors' responses: We revised our statement." "Harvest blocks, agricultural areas, residential development, and roads can all be expressed as ECA…"

4. 2858/07: Not all, sediment generated by roads and the severity thereof does not have a linear relationship to ECA

Authors' responses: We revised our statement. ", its utility in representing various types of forest disturbances including mountain pine beetle infestation, harvesting and fire in a single large watershed for hydrological studies has not been applied as far as we know"

5. 2860/07: perhaps provide reference to BEC?

Authors' responses: We added a reference for BEC. "British Columbia Ministry of Forests and Rangeland: Map of Biogeoclimatic Zones of British Columbia, Victoria, British Columbia, Canada, 2012. Accessed on May 25th.http://www.for.gov.bc.ca/hre/becweb/resources/maps/ProvinceWideMaps.html"

6. 2861/12: VRI should be identified before the acronym presented. Is there a cutblocks 2010 database or is it forest openings?

Authors' responses: We spell out VRI (Vegetation Resources Inventory). Cutblocks 2010 database is a GIS database recording harvest blocks information such as cutblock sizes and logged years. It's provided by British Columbia Ministry of Forests and Rangeland.

7. 2861/20 which industries? Or is it forest companies?

Authors' responses: Yes. They are forestry companies. We revised our statement.

8. 2862/01: "were limited except for a large burn"— map would be helpful to orient the reader.

Authors' responses: We added the location of the Long John Creek where a large burn occurred in Figure 1.

9. 2862/06: should clearly identify which watershed ECA values there represent

Authors' responses: The ECA values for each forest disturbances categories can be found in Figure 6. To make them clear, we have added more descriptions. "As shown in Figure 6, cumulative ECA was about 1% in 1975, which was then slowly increased to 10.4% and jumped from 22.4% in 2002 to 62.2% in 2009 due to salvage logging after the large-scale MPB outbreak in 2003. Up to 2009, the cumulative ECA of logging and salvage logging in response to MPB attack were 24.4 % and 22.6%, respectively. The



cumulative ECA of MPB attack without logging was 14.8% (Figure 6)."

10. 2862/13&14: Appears to show bias, it may not be severely disturbed... should the data not show whether it is or is not?

Authors' responses: We revised our statement. Forests attacked by MPB account for 70% of the watershed area. We think it's a severe forest disturbance. "Thus, the Baker Creek watershed has been disturbed by severe MPB infestation and subsequent salvage logging in the recent 10 years".

11. 2862/25: identify relationship between heights and forest canopy closure?

Authors' responses: We revised our statement as below. "The relationship between vegetation growth represented by ages or tree heights following logging and hydrological recovery rates was generally used to estimate ECA after logging for different tree species, mainly spruce and lodgepole pine forests in the watershed assessment (British Columbia Ministry of Forests and Rangeland,1999)."

12. 2863/6&7: given the importance of these coefficients, can some detail be provided on them? Example why is eca $\sim$ 18% in year 1 for sbps/sbs and 78% in year 17? Is transpiration much less important than interception and sublimation in these forest types? How about understory?

Authors' responses: We have provided more detailed information on these coefficients, MPB coefficient in particular since most readers may not be familiar with ECA and the hydrological impact of mountain pine beetle infestation. "For MPB infestation, Lewis and Huggard (2010) have developed a model to quantify the effects of MPB infestation on ECA calculation based on their monitoring in different biogeoclimatic zones. Based on their studies and inputs from local forest hydrologists, we also developed relationships between tree ages/height and hydrological recovery in SBPS, SBS and MS biogeoclimatic zones for the MPB killed forest stands. The hydrological impact of MPB infestation on forests is different from that of logging. Since dead trees remain in stands, the hydrological function of dead trees is not completely damaged as removal of trees by logging (Winkler et al., 2008). Moreover, the understory beneath MPB attacked stands and other trees not attached by MPB at overstorey can also intercept and transpire water. Thus, the alteration of hydrology due to MPB infestation was much lower than clear-cut, especially within 1-2 years after attacks. However, as dead trees lose their canopy over time, the hydrological effect of MPB attack is increased and then decreased with regeneration of young trees. For example, the ECA coefficient for the forest stand in SBS/SBPS zone is only about 15% one year after MPB attack and reaches the maximum of 75% in 18-20 years later and then drop to 10% after 60 years (Lewis and Huggard, 2010). Figure 4 provided time series of ECA coefficients for logging, fire and MPB, which was used to estimate ECA data series for each forest stand based on their disturbed area (i.e., annual clear-cut area) derived from historic disturbance records." We understand transpiration is as important as interception and sublimation. However, there is a lack of long-term and complete information on hydrological alteration due to MPB even from stand-level studies. These ECA coefficients have taken into accounts of transpiration, evaporation, interception and sublimation. They are generated by stand-level experimental studies and professional judgements. Hopefully, with more long-term site studies on the hydrological changes after forest disturbances, especially mountain pine beetle infestation, we are able to have better extrapolation of the stand-level information to large watersheds. ECA coefficient for MPB has taken understory vegetation into accounts. More details can be found in Lewis and Huggard's (2010) paper. Lewis, D. and Huggard, D.: A model to quantify effects of mountain pine beetle on equivalent clearcut area, Streamline Watershed Manag. Bull., 13(2) , 42-51, 2010

13. 2864/7: Precipitation trends were viewed at an annual.....

Authors' responses: Revised.

14. 2864/15: simply state the test used and provide references, if popularity is stated there is bound to be a reader that disagrees it is most popular.....



Authors' responses: We revised it as below. "Non-parametric tests including Mann-Kendall tau and Spearman's rho (Berryman et al., 1988; Burn and Hag Elnur, 2002; McCabe and Wolock, 2002) were applied in the trend detection, and changes with. . ."

15. 2866/25: as above, use of value-based terms will not be agreed upon by everyone, perhaps simply state the procedure used, assumptions that agree with your study, and then provide references.

Authors' responses: We revised it as below. "Given the limited long-term data in this large watershed, the Hargreaves equation (Hargreaves and Samani, 1985) was applied to compute potential evapotranspiration (Equation (2)). It requires only mean, minimum and maximum air temperature, and extraterrestrial radiation (Shuttleworth, 1993; Sankarasubramanian et al., 2001), which are available in the study watershed."

16.2867/ , significance requires presentation of p-value and test statistic

Authors' responses: We added p-value in Table 1

17.2867/11, trends appear — observations are made?

Authors' responses: We use non-parametric tests to detect the statistical significance of trends. It's not determined by simply plotting of observations to see the trends over the study period.

18.2867/24, not bolded, so is it significant? provide p-value perhaps along with rsq

Authors' responses: It's bolded. According to our test, there is a significant correlation between annual 7 day low flow and ECA. We added p-values in Table 2.

19.2868/26are these values simply reflecting thresholds in the watershed or drawn from literature

Authors' responses: These values are determined by thresholds in the study watershed. We have detected statistically significant change in annual mean flow occurred since 1999 when ECA $\geq$20%. Based on our literature synthesis, we believe that forest disturbance with ECA ≤10% is unlikely to cause any detectable hydrological changes in a large watershed. Therefore, we have divided the whole study period into three phases to explore the temporal change of hydrological responses to forest disturbance, including phase 1 (1964 to 1989, ECA ≤10 %), phase 2 (1990 to 1998, 10 %≤ECA ≤20 %), and phase 3 (1999 to 2009, ECA≥20%).

20. 2869/02: two order of magnitude increase phase 1-2 and 1 order of magnitude phase 2-3

Authors' responses: Yes. There is two order of magnitude increase from phase 1 to phase 2 because the magnitude in phase 1 is minor. There is one order of magnitude increase from phases 2 to 3 because the magnitude in phase 2 is much greater than the magnitude in phase 1. And the magnitude increase from phases 1 to 3 is even greater than that from phase 1 to phase 2, which suggests that hydrological change in phase 3 is much greater than in phase 2.

21. 2869/10: why is table 5 ECA so different than that presented in text i.e. 35% vs. up to 70.2?

Authors' responses: 35% is the average ECA for Phase 2 (from 1999 to 2009). Before 2003, ECA was less than 30%. After 2003, ECA increased dramatically and was up to 62.2% in 2009. It's reasonable to have a lower average value of ECA (35%) in Phase 2 than in the end of the study period (2009). 70.2% is the total forest area attacked by MPB from 1961 to 2009.

22. 2871/04 based on previous literature it may be a surprise? Perhaps simply state... "Annual mean flow increased......"

Authors' responses: We revised it by deleting "Not surprisingly"

23.2871/06 who predicted that mean flows .....

Authors' responses: We used "estimated" instead of "predicted". The annual mean flow change was estimated by hydrologic modeling conducted by Alila et al. (2007).



"This is consistent with the previous modeling work by Alila et al. (2007) in the Baker Creek watershed where with 34% of the watershed harvested, annual mean flows were estimated to be increased by 31%"

24. 2872/05, Clarify, unsure of the point given contrasting information.

Authors' responses: We revised our statement as below. "This suggests that the hydrological response to forest disturbances in the Baker Creek watershed is more sensitive than that in the Willow River watershed. The difference in the magnitude of annual mean flow may be responsible for different hydrological responses between two neighbouring watersheds. The annual mean flow in the Baker Creek watershed was only 103 mm, while it is 435 mm in the Willow River watershed. For example, 20 mm increment can increase the annual mean flow in the Baker Creek watershed by about 20% while it can only cause less than 5% change in annual mean flow in the Willow River watershed."

25.2872/27, Is this true? Some of the earliest forest hydrology studies identified higher summer low-flow conditions after harvesting.

Authors' responses: We understand low flows can be increased after harvesting according to some earliest studies. This can be the case in watersheds where soils are not severely damaged so reduced ET as result of harvesting can retain more soil water and thus higher low flows in low flow seasons (e.g., summer). However, low flows can be decreased after harvesting of cloud forests at higher elevations in some coastal mountains where fog drips intercepted by forest canopy from the air serve as an important source for precipitation in summers. Reduction in precipitation input accordingly decreases the runoff. More details are provided in the review paper by Bruijnzeel (2004). Moreover, for some rainfall-hydrology dominated watersheds where low flows occur in winters and peak flows in summers, low flows are expected to decline after forest harvesting (Calder, 2005). A case study in the Upper Minjiang River of Yangtze River basin can support this point (Zhang et al., 2012). In that watershed, low flow is maintained by groundwater discharge and soil water storage from wet seasons. During rainy seasons, reduction in forest canopy interception, evapotranspiration and soil infiltration after harvesting transferred more rainfall into surface and subsurface runoff and consequently more streamflow in rivers. The soil moisture was estimated to decrease by 36% after harvesting in that watershed. The dramatic decline in soil water storage in wet seasons greatly reduced available water for low flow in the dry season due to less groundwater recharging. That demonstrates the forest sponge effect that absorbs and holds huge quantities of wet season rainfall and releases the stored rainfall in dry seasons is expected to be damaged after harvesting. Accordingly, low flows were decreased after harvesting in the Upper Minjiang River of Yangtze River basin.

Bruijnzeel, L.: Hydrological functions of tropical forests: not seeing the soil for the trees? , Agric. Ecosyst. Environ., 104(1), 185-228,2004. Calder, I.R.: Blue revolution – integrated land and water resources management, 2nd ed., Earthscan, London, UK, 2005. Zhang, M., X. Wei, P. Sun and S. Liu (2012), The effect of forest harvesting and climatic variability on runoff in a large watershed: the case study in the Upper Minjiang River of Yangtze River basin, Journal of Hydrology(in press)

26. 2873/21: May want to cite recent article by Jones et al., 2012 - Bioscience which supports some of the central tenets of your paper Jones et al., 2012 Bioscience - April 2012 62(4) doi:10.1525/bio.2012.62.4.10

Authors' responses: Yes, it's a very useful paper. We cited it.

27. 2874/16, is it incredible? value-based statement may take away from your findings

Authors' responses: We deleted "incredible".

28.2875/05, jones paper provides some examples of this to support your argument

Authors' responses: We cited Jones' paper to support our argument. Please see below two paragraphs. "According to our analysis, forest disturbances and climatic variability produced opposite impacts on streamflow: forest disturbance increased streamflow



while climatic variability decreased it. For example, during the severely disturbed period from 1999 to 2009 with ECA greater than 20%, forest disturbances boosted annual mean flow, on average, by about 48.4 mm/yr, while climate variability reduced it by 35.5 mm/yr. Not surprisingly, their counteracting or cancelling effects meant that annual mean flow displayed a stable trend over the study period. These counteracting effects of forest disturbances and climate variability have also been identified by Jones et al.'s (2012) through analyses of long-term records in 35 headwater basins in the United States and Canada. Both of our studies imply that forest ecosystems have the ability of adjusting their water uses to compensate for climate variability." "As a matter of fact, in many other large watersheds experienced significant land use changes, the influence of climate variability on streamflow appeared to be weaker. For example, in the headwaters of the Yellow River Basin, China only 30% of the streamflow reduction in the 1990s was caused by climate variability while land use change was responsible for 70% of the reduction (Zheng et al., 2009). A similar result was also reported in the Chaobai River watershed, China by Wang et al. (2009) and Zhang et al. (2008). Moreover, small watershed studies yielded similar findings too. Land use changes or forest disturbances are believed to mitigate or even overwhelm climatic effects on streamflow. For example, in three long-term experimental forests (Andrews, Coweeta and Hubbard Brook), increments of daily streamflow in the late summer and early fall caused by forest harvest can be up to 300% in early years after disturbance while climate induced changes in streamflow can be 10-50% (Jones and Post, 2004; Jones et al., 2012)."

29. 2876/02: given the variety of literature you provided and your own findings... what is the safe level? Is it for all watersheds?

Authors' responses: The safe level varies among watersheds. Previous paired watershed studies suggest 20% is the threshold for detecting significant hydrological change in small watersheds (less than 100 km2). Currently, the safe level for large watersheds (>1000 km2) is very difficult to determine due to several reasons. First, large watershed studies are too limited to derive a forest disturbance threshold. Secondly, different studies use different indicators to express forest disturbance and normally focus on a single type of disturbance, which make it impossible to compare disturbance levels among different large watersheds. Third, the hydrological response of forest disturbances are watershed-specific, which can be affected by watershed attributes including geology, topography, vegetation, land use and land cover. According to our own findings, the safe levels for the Willow River watershed and the Baker Creek watershed in B.C. interior can be 20-25% while for the Bowron River watershed it can be above 30%. Thus, more case studies are needed to determine the thresholds of ECA for significant hydrological changes.

Please also note the supplement to this comment:
http://www.hydrol-earth-syst-sci-discuss.net/9/C1971/2012/hessd-9-C1971-2012-supplement.pdf

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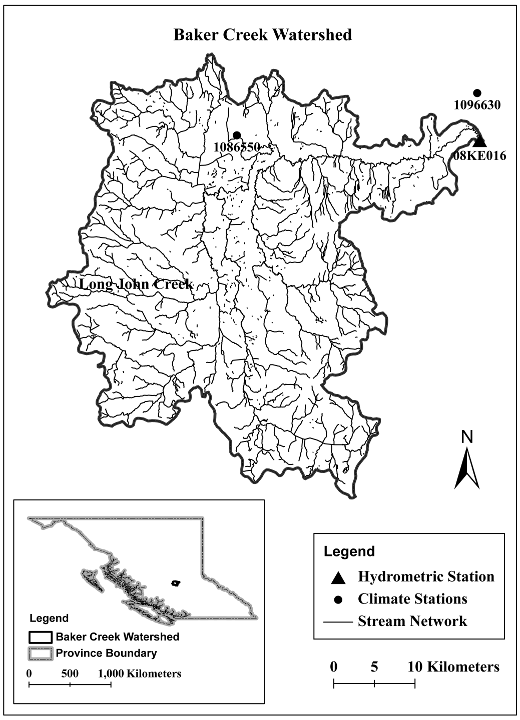


**Fig. 1.** Location of the study watershed in the central interior of British Columbia, Canada