Impact of DEM Resolution on Topographic Indices and Hydrological Modelling Results

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EXTENDED ABSTRACT

Topography is an important land-surface characteristic that affects most aspects of the water balance in a catchment, including the generation of surface and sub-surface runoff; the flow paths followed by water as it moves down and through hillslopes and the rate of water movement. All of the spatially explicit fully distributed hydraulic and hydrological models use topography (represented by the DEM of the area modelled) to derive bathymetry. DEM is also used to derive some other key information critical in fully distributed hydraulic and hydrological models.

In most of the distributed modelling implementations, relatively large DEM grid cells make up the model domain in order to reduce the computation time. This is to allow quick model calibrations and model sensitivity analysis but also, in operational mode, it allows model simulations in real time. A major disadvantage of the use of low resolution input data is the loss of important small-scale features that can seriously affect the modelling results. If the input DEM is at a higher grid resolution, during the transformation or re-sampling of the original DEM data to a lower model resolution, important topographic details are lost mainly as a result of averaging. If the input DEM is already at a low resolution, it does not represent the actual on-ground topographic features which might significantly affect the accuracy and reliability of the results from the modelling exercise.

There are numerous studies reported in literature which compare spatial indices derived from different coarse resolution DEM's (eg. 100m and 1000m grid cell resolution) and researchers have also investigated the effect of using coarse resolution DEM on the results from hydrological and hydraulic modelling. Most or almost all of the reported studies focus on coarse resolution DEM (100m or above). With higher resolution DEM's such as LiDAR (Light Detection and Ranging) becoming more readily available and also with the advancements in computing facilities which can handle these large datasets, there is a need to quantify the impact of using these different resolution DEM's (eg. 1m against 10m or 25m) on the modelling results and the loss of accuracy and reliability of the results as we move from high resolution to coarser resolution.

This paper presents the results from an investigation where we re-sampled the 1m LiDAR DEM in steps (2m, 5m, 10m, and 25m) and compared the different spatial indices derived from these different resolution DEMs against the ones derived from the base data (1m LiDAR DEM). By re-sampling to coarser grid cell size, averaging across increasingly larger domains is realised and has resulted in an increased loss of detailed topographic properties that affect the spatial indices derived from the DEM. We also compared these outputs against the widely available and most commonly used 25m DEM across NSW, which is derived from contour maps. The results indicate that the quality of DEM-derived hydrological features is sensitive to both DEM accuracy and resolution. The contour derived 25m DEM across NSW has substantial differences when compared to the 1m LiDAR DEM and also with the 25m coarsened LiDAR DEM. The results also indicate that the loss of details by re-sampling the higher resolution DEM to lower resolution are much less compared to the details captured in the widely available low resolution DEM derived from contour maps. As such, where available, the higher resolution DEM should be used instead of the coarse resolution one.

1. INTRODUCTION

Digital Elevation Models (DEMs) are the digital representation of natural topographic as well as man-made features located on the surface of the earth. For the last few decades, DEMs are widely used for resource management, urban planning, transportation planning, earth sciences, environmental assessments, and Geographic Information System (GIS) applications. The hydrologic community is also moving into a new era of using GIS technology (with DEM of the area of interest being the primary and necessary input) in spatially explicit eco-hydrological, biophysical, hydrodynamic and hydraulic modelling.

Hydraulic and distributed hydrological modelling as well as water resource management commonly requires investigation of landscape and hydrological features such as terrain slope, drainage networks, drainage divides, and catchment boundaries. Digital Elevation Models offer an efficient way to represent ground surface and allow automated direct extraction of hydrological features, thus bringing advantages in terms of processing efficiency, cost effectiveness, and accuracy assessment, compared with traditional methods based on topographic maps, field surveys, or photographic interpretations.

In distributed hydrological modelling, output to a large extent is affected by model input such as the DEM and other topography related properties such as slope gradients, slope aspects and drainage density. Researchers have found that DEM quality and resolution significantly affect the accuracy of any extracted hydrological features (Kenward et al., 2000). Model inputs such as the hydraulic roughness, which are simulated at the scale of the DEM elements, change with DEM resolution and as such also affect simulation results.

Quinn et al. (1991) asked a question ". . . distributed modelling of hillslope flows will require a grid scale much smaller than the scale of the hillslope, but how much smaller?" This question is applicable to every hydrologic application where DEM is the primary input. It's a well-understood fact that most DEMs have generalisations of the land surface built into them. If these generalisations are within the spatial range of the processes that are operating in the landscape of interest, there is no problem. However, if the generalisations are greater than the resolution of landscape processes, any results or indices derived from DEMs must be treated with caution.

In some flat areas and for some processes a grid cell resolution of 25m or even higher is adequate to capture the scale of surface processes. Whereas in other areas the resolution required may be as high as 1m. In other words, landscape process scale is the key driver in determining useful grid cell resolution. Along with appropriate grid cell resolution, the vertical accuracy of the grid cell elevation is also a critical factor as a small error in grid cell elevation can result in totally different and incorrect model predictions and values of the spatial indices derived from the DEM.

The issue of scale in the context of indices derived from image data has been discussed in many papers. Gallant and Hutchinson (1996) point out that the grid resolution of DEMs can profoundly influence the spatial patterns of attributes derived from them, and also influence models built from these attributes. Warren et al. (2004) compared slopes measured in the field with those derived from DEMs, and found that higher resolution DEMs (1m) produced much better results than lower resolution DEMs (12m).

In distributed hydrological modelling, the impact of original DEM resolution on modelling results and implications of re-sampling higher resolution DEM to coarser resolution to allow quick model simulations in the context of modelling results has also been discussed in many papers (Horritt and Bates, 2001; Horritt and Bates, 2002). Horritt et al. (2002) evaluated the flood simulation results as obtained from a 1D raster based model and a 2D model with finite element discretisation. The results indicated that simulated topographic properties had a major effect on simulation results and topography is a major factor determining flood inundation patterns as they develop over time.

There are numerous studies (Wolock and McCabe, 2000; Jenson, 1991; Hutchinson and Dowling, 1991) reported in literature which compare spatial indices derived from different coarse resolution DEM's (eg. 100m and 1000m grid cell resolution). With higher resolution DEM's such as LiDAR becoming more readily available, there is a need to quantify the effect of using high resolution DEM's on the values of spatial indices derived from them. This paper presents the results from an investigation where we re-sampled the 1m LIDAR DEM in steps (2m, 5m, 10m, and 25m) and compared the different spatial indices derived from these different resolution DEMs against the ones derived from the base data (1m LiDAR DEM). We also compared these outputs against the widely available and most commonly used 25m DEM across NSW, which is derived from contour maps.

2. STUDY AREA

The study area is within the Koondrook-Perricoota Forest (KPF). KPF is the NSW component of the Ramsar listed Gunbower-Perricoota Forest, which is the second largest contiguous area of floodplain forest in Australia. The KPF covers an area of approximately 320 km^2 on the NSW side of the Murray River between Echuca-Moama and Barham-Koondrook (see Figure 1).

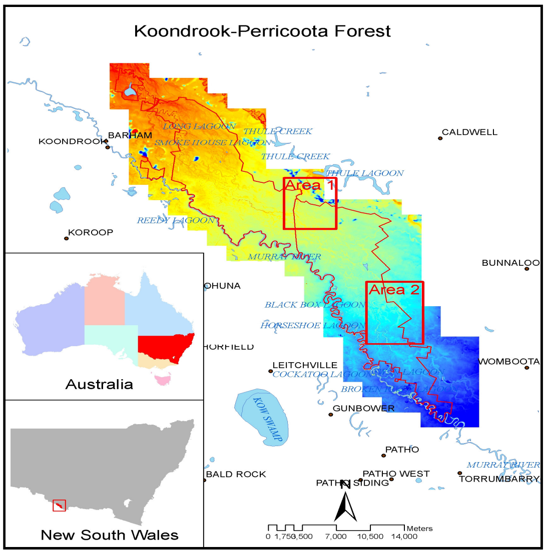

Figure 1. Location of study area

2.1. Data

The 1m LiDAR DEM for KPF used in this study is derived as part of the Southern Murray Darling Basin (SMDB) LiDAR project and is sourced from MDBC. For the analysis presented in this paper, we only focused on the 1m DEM for last return. The results from a detailed statistical analysis indicate that the 1m LiDAR DEM is a reasonably accurate representation of the ground elevations (Vaze and Teng, this conference).

The 25m resolution DEM used in this study is available for the whole of NSW and is supplied by the New South Wales Land Information Centre (Statewide digital elevation model data, 1999). This DEM is derived from contour and drainage data sourced from the New South Wales Topographic Map Archive (pre 1995). Predominantly 10 metre and 20 metre contours are used as source data. The metadata states that the initial digital contour collection is within 0.3mm of map transparencies at scales of 1:25000, 1:50000 and 1:100000. Vertical accuracy of the DEM is to within 0.5 of the source document contour interval.

2.2. Methods / Analysis

The entire KPF forest lies within the Murray flood plains, which is a relatively flat area. There are only some small areas within the forest, which are relatively steeper, compared to the rest of the forest. Two reasonable size areas within the KPF (Area 1 around 37 km^2 and Area 2 around 42 km^2, see Figure 1) were selected such that Area 1 is in the steeper parts and Area 2 has very low relief. The analysis described below was carried out separately on these two areas and the whole KPF.

The 1m LiDAR DEM was re-sampled in steps to generate 2m, 5m, 10m, and 25m DEM's. Two spatial indices, elevation and slope, derived from these different resolution DEM's were compared with the respective values for the original 1m LiDAR DEM and to the commonly available 25m DEM across NSW which is derived from contour maps. For each of the DEM's, basic spatial analysis (including calculation of flow direction, flow accumulation, stream network, basin/watershed) was also undertaken and the results were compared against the ones derived from the base data (1m LiDAR DEM).

3. RESULTS AND DISCUSSION

For each of the two areas (Area 1 and Area 2) and for the entire KPF which include both of these areas, grid cell elevation and slope statistics were computed for the original 1m LiDAR DEM, the re-sampled 2m, 5m, 10m, 25m LiDAR DEM's and for the 25m NSW DEM. In Figure 2, minimum, maximum and mean grid cell elevation for all the DEM's are plotted separately for the 3 areas. Figure 2 also shows the maximum and mean grid cell slope for the all the above cases. Throughout the discussion below, the 1m LiDAR DEM and the re-sampled 2m, 5m, 10m and 25m LiDAR DEM's will be referred to as 1m, 2m, 5m, 10m and 25m DEM's respectively. The 25m DEM derived from contour maps will be referred to as the 25m NSW DEM.

It can be clearly seen from Figure 2 (Area 1 – Elevation) that the minimum grid cell elevation increases slightly as we move to coarser resolution from 1m until 10m (a total difference of 0.3m). The difference increases substantially when we compare the 10m and 25m resolution DEM's (2m). There is no difference in the maximum grid cell elevation for the 1m and 2m DEM's and it decreases slightly as we move to coarser resolution up to 25m (a total difference of 0.2m between 1m and 25m). And there is no change in the mean grid cell elevation as we move from 1m to 25m.

The results for minimum and mean elevation for Area 2 (see Figure 2, Area 2 – Elevation) are almost identical to those for Area 1 except that the difference in minimum elevation between the 10m and 25m DEM's is much smaller (0.7m) compared to that for Area 1 (2m). When comparing maximum grid cell elevations, there is practically no difference as we move from 1m to 2m but the difference increases by 0.5m with each coarsening of the DEM from 2m to 25m.

The elevation statistics for the entire KPF (Figure 2, Entire Forest – Elevation) shows practically no difference in minimum, maximum and mean grid cell elevation as we coarsen the DEM from 1m to 25m. Between 1m and 25m resolutions, there is a slight increase in minimum grid cell elevation and a slight decrease in the maximum grid cell elevation. The 25m NSW DEM used in this analysis do not cover the entire forest and so the comparison for the entire forest does not include the statistics for this data set.

Figure 2 (Area 1 – Slope) shows that the maximum grid cell slope decreases sharply with coarsening. The maximum slope value drops from 58.9 to 45.5 as we move from 1m to 2m and it drops down to 9.4 for the 25m DEM. The mean grid cell slope also decreases sharply as we move to coarser resolution. As expected, the minimum grid cell slope for all the resolutions is always equal to 0. The grid cell slope statistics for Area 2 and the entire forest are quite similar to those for Area 1.

The maximum grid cell slope values for all the resolutions for Area 1 are higher than those for Area 2. As mentioned earlier, Area 1 is relatively steep compared to Area 2 and the difference in maximum and minimum grid cell elevation for the 1m DEM for Area 1, 19.7m is much higher than that for Area 2, 7.3m. For both Area 1 and Area 2 and for the entire forest, the difference between the maximum and minimum grid cell elevation decreases as we move to coarser resolution (both minimum and maximum elevation approaching the mean elevation) basically because of averaging over larger areas making the DEM "smoother".

When comparing 25m LiDAR DEM with the 25m NSW DEM, it can be clearly seen that there are major differences between the two DEM's. For Area 1, the minimum and maximum grid cell elevations for the NSW DEM are 3m higher and 12.5m lower compared to the corresponding elevation values for the 25m LiDAR DEM. For Area 2, the minimum elevation for the two DEM's is almost same but both the mean and maximum elevation for the NSW DEM are more than 1m lower than the same values for the 25m LiDAR DEM. Another interesting thing to note is that the difference between the minimum, maximum and mean elevation values for the 25m NSW DEM for Area 1 is negligible (and very different to the corresponding values for the 25m LiDAR DEM) whereas the same differences for Area 2 (relatively flat compared to Area 1) are quite similar to the 25m LiDAR DEM. As expected, the maximum grid cell slope for the 25m LiDAR DEM is always much higher (9.4 for Area 1 and 3.8 for Area 2) compared to the 25m NSW DEM (0.6 for Area 1 and 0.3 for Area 2).

Figure 3 compares the stream networks and watersheds generated for Area 1 and Area 2 using 1m, 10m and 25m LiDAR DEM's. The areas where the stream network is significantly different for the different resolution DEM's are circled in red. For Area 1, the area of the largest watershed (shown in blue) changes from 17.9 km2 to 17.95 km2 as we move from 1m resolution to 10m and to 17.1 km2 for the 25m resolution DEM. As such there is practically no difference in terms of the watershed areas between the different resolutions. But there is a significant change in the shape of the blue catchment when comparing the 3 watersheds. The small difference in the catchment areas for the blue catchment between different resolutions is more of compensating differences.

There is a major difference in the watershed boundaries for the 1m, 10m and 25m DEM's (blue catchment) with the most significant difference towards the top of the blue catchment. Surprisingly, in this area, the results in terms of shape are similar for the 1m and 25m resolutions with the 10m resolution differing totally from the other two. There are also quite significant differences between the 3 different resolution outputs in terms of the total number and size and shape of the smaller watersheds (in green, light yellow and orange). For example, there is a small green watershed at the bottom middle part of 10m and 25m resolutions (green) whereas it is not present at all for the 1m resolution (and all that area is actually part of the big blue catchment). The results for stream network and watershed boundaries for the different resolution DEM's for Area 2 are quite similar to that for Area 1.

The different watersheds and stream network for the entire KPF generated using 1m and 10m LiDAR DEM are shown in Figure 4. The area where the difference in the stream network generated using 1m and 10m resolution causes the change in the contributing areas for the two sub-catchments is circled in red. For both 1m and 10m resolution, the small sub-catchment towards the right side of the forest has similar shape and area. But there is a major difference between the two resolutions for the other two sub-catchments. The results clearly demonstrate the effect different resolution DEM's can have on the modelling results. If the input DEM is 1m resolution, it will make the model to force water through the forest according to the left hand side map whereas if the input DEM is at 10m resolution the flow paths will be as in the right hand side map.

All the results discussed above clearly show that the accuracy and resolution of the input DEM has serious implications on the results from hydrological modelling and on the values of the spatial indices derived from the DEM. The result also indicate that the loss of details by re-sampling the higher resolution DEM to coarser resolution are much less compared to the details captured in the commonly available coarse resolution DEM derived from contour maps.

4. CONCLUSIONS

The quality of DEM-derived hydrological features is sensitive to both DEM accuracy and resolution. There are significant differences between the elevation and slope values derived from high resolution LiDAR DEM and coarse resolution contour derived DEM. Watershed boundaries derived from these two DEM types are also quite different. In spite of the same resolution for the 25m NSW DEM and the 25m re-sampled LiDAR-derived DEM, higher accuracy LiDAR DEM gave a more detailed delineation of watersheds. The results clearly indicate that the LiDAR derived DEM with high accuracy and high resolution offers the capability of improving the quality of hydrological features extracted from DEM's.

The results also suggest that if higher resolution DEM is available and because of limitations (with the computing facilities or model run time or the limitation of the model itself in handling large number of grids cell) the high resolution DEM can not be used, it should be re-sampled to lower resolution and used instead of using the contour derived low resolution DEM. The results clearly indicate that the loss of details by re-sampling the higher resolution DEM to coarser resolution are much less compared to the details captured in the commonly available coarse resolution DEM derived from contour maps.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Gallant, J.C. and Hutchinson, M.F. (1996), Towards an understanding of landscape scale and structure, In Proceedings, Third International Conference /Workshop on Integrating GIS and Environmental Modeling, Santa Fe, NM, January 21-26, 1996. Santa Barbara, CA: National Center for Geographic Information and Analysis.

Horritt, M.S., and Bates, P.D., (2001). Effects of spatial resolution on a raster based model of flood flow. Journal of Hydrology. 253, pp. 239-249.

Horritt, M.S., and Bates, P.D., (2002) .Evaluation of 1D and 2D numerical models for predicting river flood inundation. Journal of Hydrology. 268, pp. 87-99.

Hutchinson, M. F. and Dowling, T. I. (1991). A continental hydrological assessment of a new grid-based digital elevation model of Australia. Hydrological Processes 5: 45-58.

Jenson, S.K. (1991) Applications of hydrological information automatically extracted from digital elevation models, Hydrological Processes 5: 31-44.

Kenward, T., Lettenmaier, D. P., Wood, E. F. and Fielding, E. (2000), Effects of Digital Elevation Model Accuracy on Hydrologic Predictions, Remote Sensing of Environment, 74(3): 432-444.

Quinn, P., Beven, K., Chevallier, P. and Planchon, O. (1991), The prediction of hillslope flow paths for distributed hydrological modelling using digital terrain models, Hydrological Processes 5: 59-79.

Warren, S.D., Hohmann, M.G., Auerswald, K. and Mitasova, H. (2004), An evaluation of methods to determine slope using digital elevation data, Catena 58: 215-233.

Warren, S.D., Hohmann, M.G., Auerswald, K. and Mitasova, H. (2004), An evaluation of methods to determine slope using digital elevation data, Catena 58: 215-233.

Wolock, D.M. and McCabe, G.J. (2000) Differences in topographic characteristics computed from 100- and 1000-m resolution digital elevation model data, Hydrological Processes 14: 987-1002.

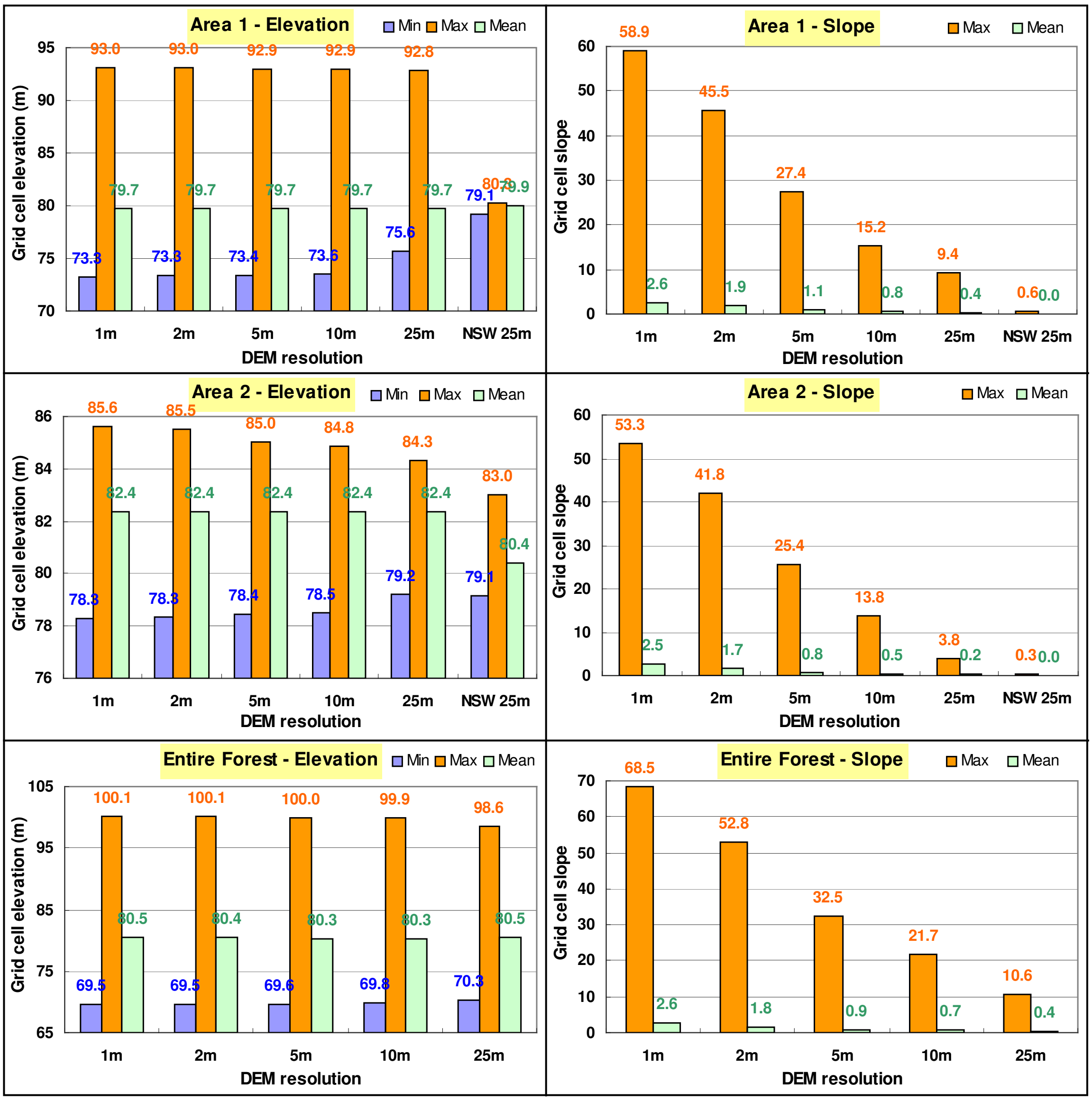

Figure 2. Variation in minimum, maximum and mean grid cell elevation and slope for 1m, 2m, 5m, 10m, 25m LiDAR and 25m NSW DEM for Area 1, Area 2 and the entire forest

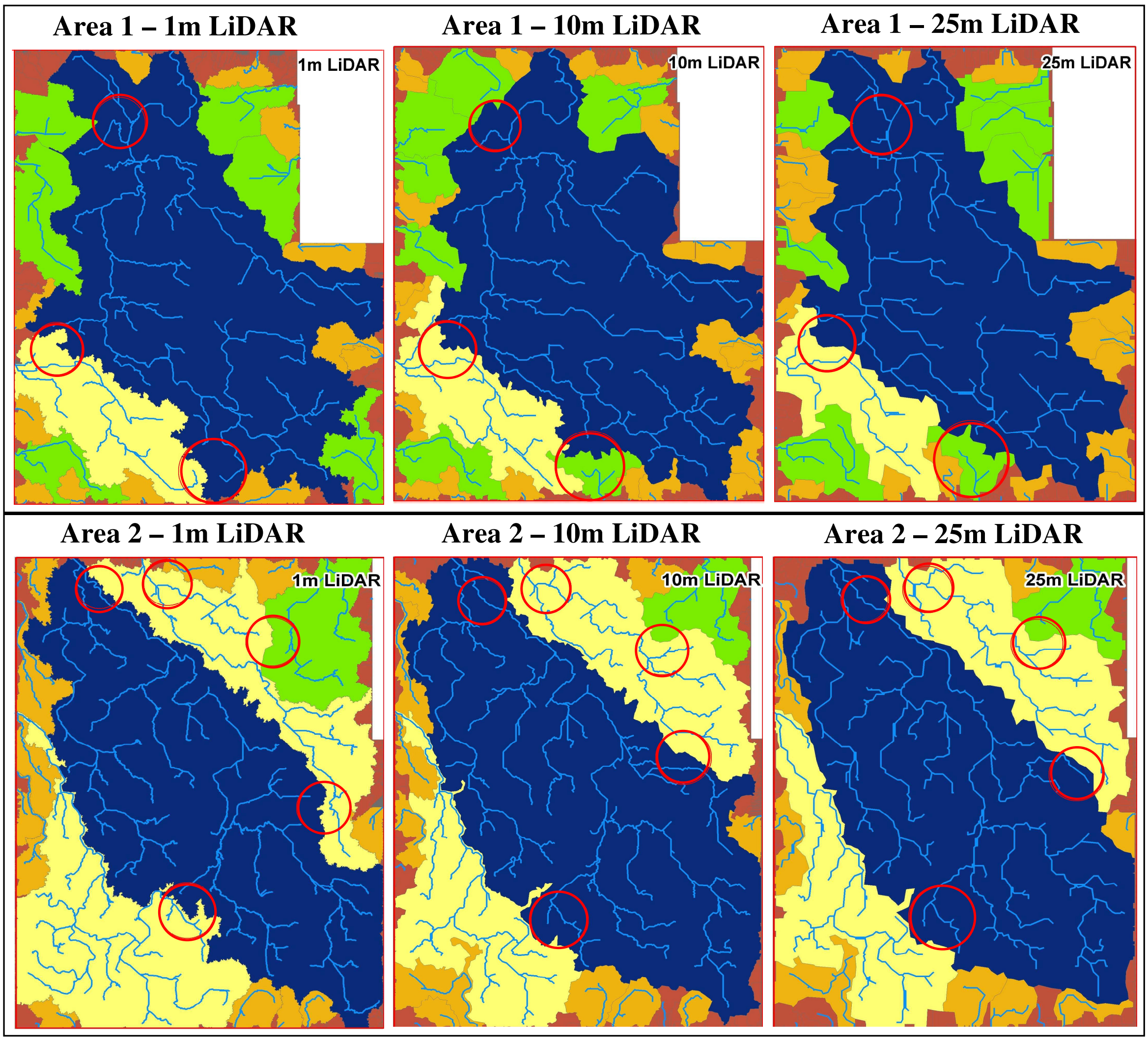

Figure 3. Stream network and watersheds for Area 1 and Area 2 derived from different resolution DEM's

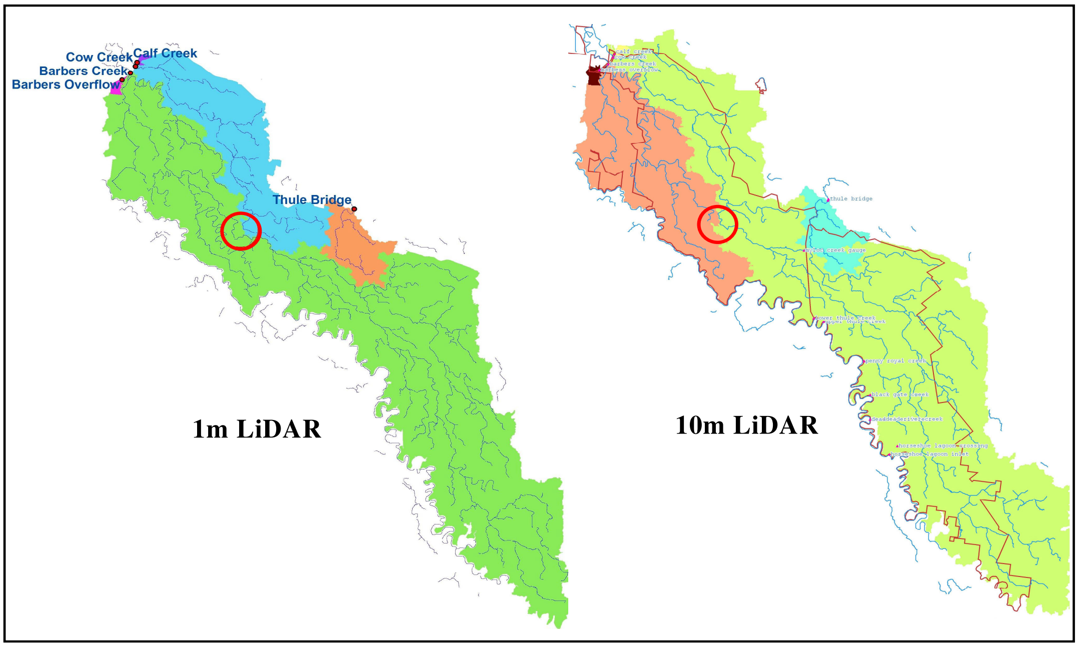

Figure 4. Stream network and watershed for the entire KPF derived from different resolution DEM's