High Resolution LiDAR DEM – How good is it?

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EXTENDED ABSTRACT

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 the DEM of the area of interest being the primary and necessary input) in spatially explicit eco-hydrological, biophysical, hydrodynamic and hydraulic modelling approaches to answer critical on-ground questions such as choosing appropriate areas within catchments to implement different landuse changes and land management options. Almost all of the applications including water resource management and hydrological modelling require high resolution DEMs because the accuracy of DEMs significantly affects the accuracy of hydrological predictions.

High resolution DEMs are not available across most of Australia and around the world. Improvements in gathering and displaying elevation data make it economically feasible to address the chronic lack of high-resolution terrain data. LiDAR (Light Detection and Ranging), a relatively new technology, offers advantages over traditional methods for representing a terrain surface. The advantages refer to accuracy, resolution, and cost. One of the most attractive characteristics of LiDAR is its very high vertical accuracy, which enables it to represent the Earth surface with high accuracy.

The NSW Department of Water and Energy (DWE) and NSW Department of Environment and Climate Change (DECC) along with Murray Darling Basin Commission and Department of Commerce is undertaking the Hydraulic Modelling of the flood inundation patterns and overland flow in the Koondrook-Perricoota Forest (KPF). MIKE FLOOD with bathymetry derived from 1m LiDAR DEM is used to reproduce the observed inundation patterns for historical flood events (model calibration/validation) and to predict the inundation patterns (areas, depths and flow velocities) across the KPF under the proposed new inflow regime.

This paper presents the results from a statistical analysis undertaken to investigate the accuracy of the 1m LiDAR DEM by comparing the LiDAR elevations at more than 12000 points (in steep as well as flat areas) with on-ground field survey elevations. The field survey points used to quantify the accuracy of the LiDAR data have a vertical accuracy of 1mm. The Root Mean Square Error (RMSE) and Percentile values from the statistical analysis indicate that the 1m LiDAR DEM is a reasonably good representation of the ground elevations for any detailed hydraulic and hydrological modelling exercise.

1. INTRODUCTION

One of the most commonly used and widely available basic spatial information is Digital Elevation Model (DEM). All of the spatially explicit fully distributed hydraulic and hydrological models use the DEM of the area modelled to derive bathymetry, which is a critical input in terms of model predictions. DEM's are also used to derive some other key information critical in fully distributed hydraulic and hydrological models, such as lateral multiple flow paths, accumulation and dispersion of water and solutes from hazard areas, Compound Topographic Index (CTI) (also referred to as Topographic Wetness Index, TWI) and catchment boundary delineations. DEM's are also used in association with other spatial layers such as soil landscape mapping to provide more detailed information such as estimates of soil depth, soil material/horizon distribution and soil moisture storage capacity in different parts of the landscape (Teng et al, in press).

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 small as 1m. In other words, landscape process scale is the key driver in determining useful grid cell resolution scale.

Along with appropriate grid cell resolution, the vertical accuracy of the grid cell elevation is also a critical factor as a small error in the elevation can result in totally different and incorrect model predictions. This is because the DEM of the modelled area with the given grid cell resolution and vertical accuracy are critical drivers for most of the hydraulic and hydrological processes.

Fryer et al. (1994) asked if earth scientists are fully aware of the limitations of DEMs, and note that errors in a DEM will propagate through to model predictions. Problems with DEM accuracy, both spatial and in elevation, are well documented in the literature. It is necessary to take into account the origin of the data in DEMs. Many DEMs are derived from the contours and spot heights on topographic maps. A DEM derived from, say, a map with a 20m contour interval, will have a ground resolution unlikely to be better than 20m, no matter what the grid size of the DEM. That is to say, on hill slopes of 45^o the ground resolution of the DEM will be 20m, but because most slopes, at least in Australia, are much gentler that that, the ground resolution will in reality be greater than 20m.

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. Schoorl et al. (2000) discuss the implications of varying DEM resolution on the numerical values of attributes derived from them. For example, they showed that modelled soil loss increased with coarser resolutions. In another example, 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). They commented that this variation can lead to widely varying estimates of environmental factors such as soil erosion. Wilson and Gallant (2000) state that "additional work is required to identify the important spatial and temporal scales and the factors that influence or control the processes and patterns operating at particular scales".

The most commonly used DEMs in Australia and across the world are normally produced by using elevation data mainly derived from existing contour maps at varying scales ranging from 1:25,000 to 1:100,000 and if available, digital stereo capture, providing a terrain surface representation with a horizontal resolution of 20 to 50 metres. Although, a good starting dataset, these DEMs have substantial inaccuracies associated with them, both because of the scale of the original contour maps used to derive them and also because of digitising errors. For example, the Victorian DEM (Vicmap Elevation) with a horizontal resolution of 20 metres has standard deviations, vertical and horizontal, of 5 metres and 10 metres respectively (Land- Victoria, 2002).

Improvements in gathering and displaying elevation data make it economically feasible to address the chronic lack of consistent high-resolution terrain data. LiDAR (Light Detection and Ranging), a relatively new technology, offers advantages over traditional methods for representing a terrain surface. The advantages refer to accuracy, resolution, and cost. One of the most attractive characteristics of LiDAR is its very high vertical accuracy which enables it to represent the Earth's surface with high accuracy. LIDAR is one of the few systems that collects data from all points, and also has the potential to produce DEMs with 1-2m horizontal resolution.

Almost all of the applications including water resource management and hydrological modelling require high quality DEMs because the accuracy of DEMs does affect the accuracy of hydrological predictions. This paper presents the results from a statistical analysis carried out to investigate the accuracy of the 1m LiDAR DEM by comparing the elevations at 12000 + points with field survey points which have a reported vertical accuracy of 1mm.

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 Gunbower-Perricoota Forest has been identified by the Murray Darling Basin Ministerial Council as one of six significant ecological assets (SEA) along the Murray River. The Koondrook-Perricoota Forest is located some 3 km east of Barham in south-west NSW (see Figure 1).

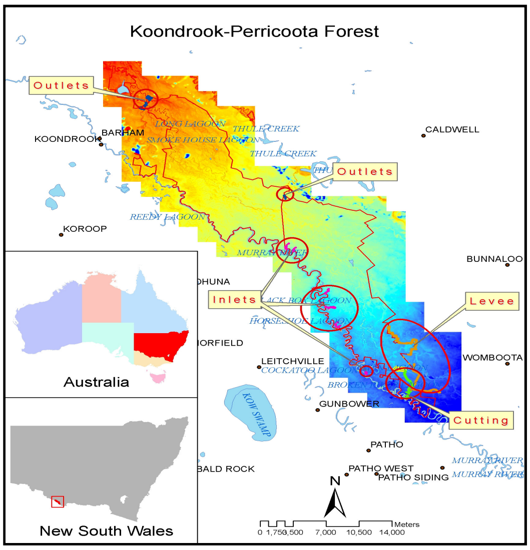

Figure 1. Location of study area with the survey areas circled in red

The KPF straddles two Central mapping 1:50000 Topographic map sheets, Barham (7726-I and IV) and Keely (7726-S). The KPF covers an area of approximately 32,000ha on the NSW side of the Murray River between Echuca-Moama and Barham-Koondrook.

Figure 2. One of the surveyed KPF inflows used in the analysis

2.1. Data

Murray Darling Basin Commission (MDBC), Australia commissioned Department of Sustainability and Environment (DSE), Victoria in 2001 to collect high resolution terrain data as part of the Southern Murray Darling Basin (SMDB) LiDAR Project. The project covers the southern extent of the Murray Darling Basin within the proximity of the Murray River and the derivatives include 1m and 10m DEM (height) for first and last (ground) return and 1m intensity raster for first return. The LiDAR DEM for KPF used in this study is derived as part of the SMDB project and is sourced from MDBC. For the analysis presented in this paper, we focused on the 1m DEM for last return.

A field survey was carried out by Department of Commerce, NSW that covered the cross-sections of all the inflow channels from the Murray River into the KPF (see Figure 2), the cross-sections of all the outflow channels from the KPF and also other major features within the KPF. Higher concentrations of points were collected to capture more important topographic features such as channel banks, creek beds and local drainage basins, and lower concentrations of points were collected in the more featureless parts of the survey area. The field survey gathered elevations at more than 12000 points (in steep as well as flat areas) with a vertical accuracy of 1mm.

2.2. Methods / Analysis

Along with the basic statistics (minimum, maximum and mean difference), the Root Mean Square Error (RMSE) and the Percentile method were also used to evaluate the accuracy of the LiDAR elevations when compared to the field survey elevations.

The RMSE method is based on the removal of errors using the 3 sigma rule. The 3 sigma rule removes all errors greater than 3 standard deviations until either, the 5% of data has been removed, or there are no more errors greater than 3 sigma. Once these errors have been removed, the vertical accuracy is reported at 68% confidence level as direct value of the RMSE and at 95% confidence level as per the formula: Accuracy = RMSE * 1.9600.

The percentile method involves ordering the absolute difference between the feature survey and LiDAR DEM's and removing the worst 5% of data than selecting the next largest error as the 95th percentile. This is than repeated for the 68th percentile by removing the worst 32% and selecting the next worst error as the 68th percentile value.

3. RESULTS AND DISCUSSION

For each of the 12000 + field survey points, the survey elevations were compared with the elevations derived from the 1m LiDAR DEM. The majority of the survey points (more than 10000) are located along the proposed cutting alignment and the existing Levee. Table 1 summarises the minimum, maximum and mean difference in elevations between the two datasets for all the 6 KPF areas (circled in red, Figure 1). As expected, the minimum difference is always almost zero and the mean difference is always less than 0.4m. When considering the maximum difference, the greatest difference is for the inflow areas (about 3.2m) with the second biggest one for the Levee (about 2.5m).

Table 2 summarises the RMSE and Percentile method differences between the field survey elevations and the 1m LiDAR DEM derived elevations. The biggest difference in the RMSE analysis at the 68 % confidence level is close to 0.4m and at the 95 % confidence level it goes as high as 0.8m. For the percentile method, the biggest difference at 68th percentile is again close to 0.4m and at 95th percentile is just above 1.4m.

The metadata statement associated with the LiDAR DEM provides some estimates of RMSE and Percentile values for ground truthing at 736 points spread across 5 locations. The reported average RMSE value at the 68 % confidence level is 0.17m and at the 95 % confidence level the value is 0.33m. The average 68th percentile is 0.16m and the average 95th percentile is 0.35m.

The difference between survey elevations and the 1m LiDAR DEM derived elevations for both RMSE and Percentile method are much higher in this analysis compared to the values reported in the LiDAR DEM metadata statement. It should be noted that the original LiDAR DEM covers a much bigger area compared to the area of the forest and so the 736 survey points is a very small sample. This analysis is based on more than 12000 survey points and it covers both relatively flat and very steep areas.

In Figure 3, for each of the 6 KPF areas surveyed, the survey elevation for each point is plotted (x-axis) against the elevation for the same point derived from the 1m LiDAR DEM (y-axis). Figure 4 shows the difference between the survey and LiDAR derived elevations for four cross-sections along the cutting and one cross-section for one of the outflows. It can be clearly seen from both the figures (especially Figure 3) that the two datasets are in reasonably good agreement in relatively flat areas such as Cutting, Bullock Head Creek and the Outlet. The biggest difference between the two datasets is for the Levee with some scatter for Inflow and Swan Lagoon. The survey elevations for quite a few points are much higher than the LiDAR derived elevations for the Levee.

The Levee and inflow are the steepest areas out of the 6 used in this analysis. Inflow (see Figure 2) is quite narrow channel incised deep within the forest surface and the Levee is 1m to 3m wide and raised above the natural forest surface by about 1 to 2m with steep side slopes. The bigger differences for these two areas are mainly because survey elevations are for a point whereas the 1m LiDAR DEM derived elevations are average values for 1m x 1m grid cell. As expected, the differences between the two datasets are highest in steep areas with higher gradient.

The results from this analysis carried out to compare the survey elevations with the LiDAR DEM derived elevations, show that there are small differences between the two datasets but LiDAR DEM is a reasonably good representation of the actual ground surface compared to other commonly used DEM's. The comparison between 1m LiDAR DEM and the 25m DEM available for whole of NSW and widely used for distributed modelling is presented in another paper (Vaze and Teng, this conference).

4. CONCLUSION

LiDAR is a remote sensing technology that is increasingly being used to map forested terrains. LiDAR has the ability to measure elevations more accurately than preexisting mapping techniques and to create good quality terrain maps due to its small diameter laser beam footprint, even under forest canopy.

The results from the statistical analysis (Root Mean Square Error (RMSE) and Percentile values) undertaken to investigate the accuracy of the 1m LiDAR DEM by comparing the LiDAR elevations at more than 12000 points with on-ground field survey elevations (with a vertical accuracy of 1mm) indicate that the 1m LiDAR DEM is a reasonably good representation of the ground elevations for any detailed hydraulic and hydrological modelling exercise.

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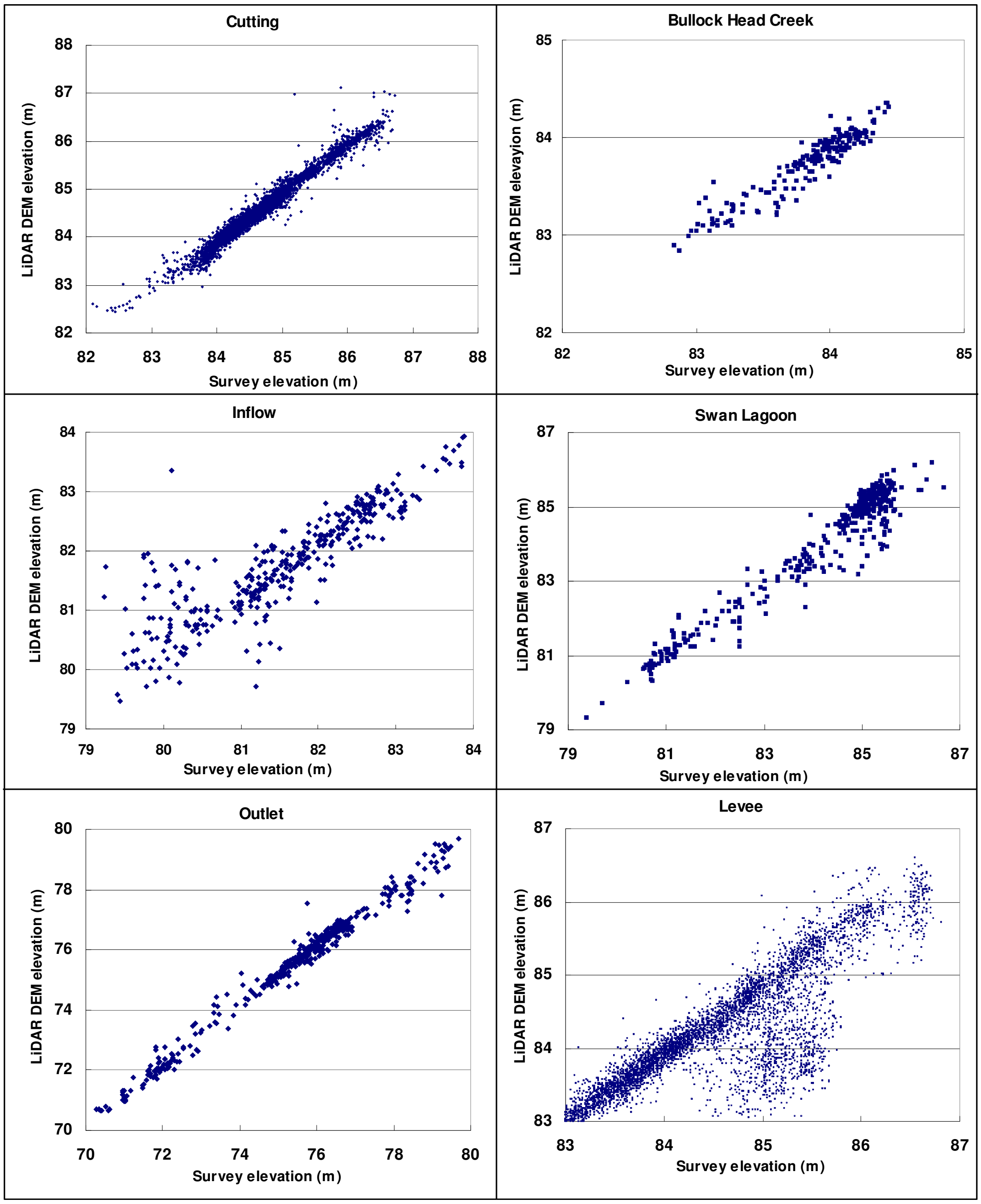

Figure 3 Comparison of Survey and LiDAR DEM derived elevations for the six areas surveyed

Table 1 Basic comparison statistics

Feature Survey Points	Number of points used	Difference (m) (Survey -LiDAR)		
		Minimum	Maximum	Mean
Cutting	4836	0.0001	1.7767	0.126
Bullock Head Creek	208	0.0028	0.4083	0.1349
Inflow	366	0.0026	3.2357	0.3715
Swan Lagoon	425	0.0006	1.7674	0.2819
Outlet	447	0.0007	1.7934	0.2284
Levee	5378	0.0001	2.4709	0.3378

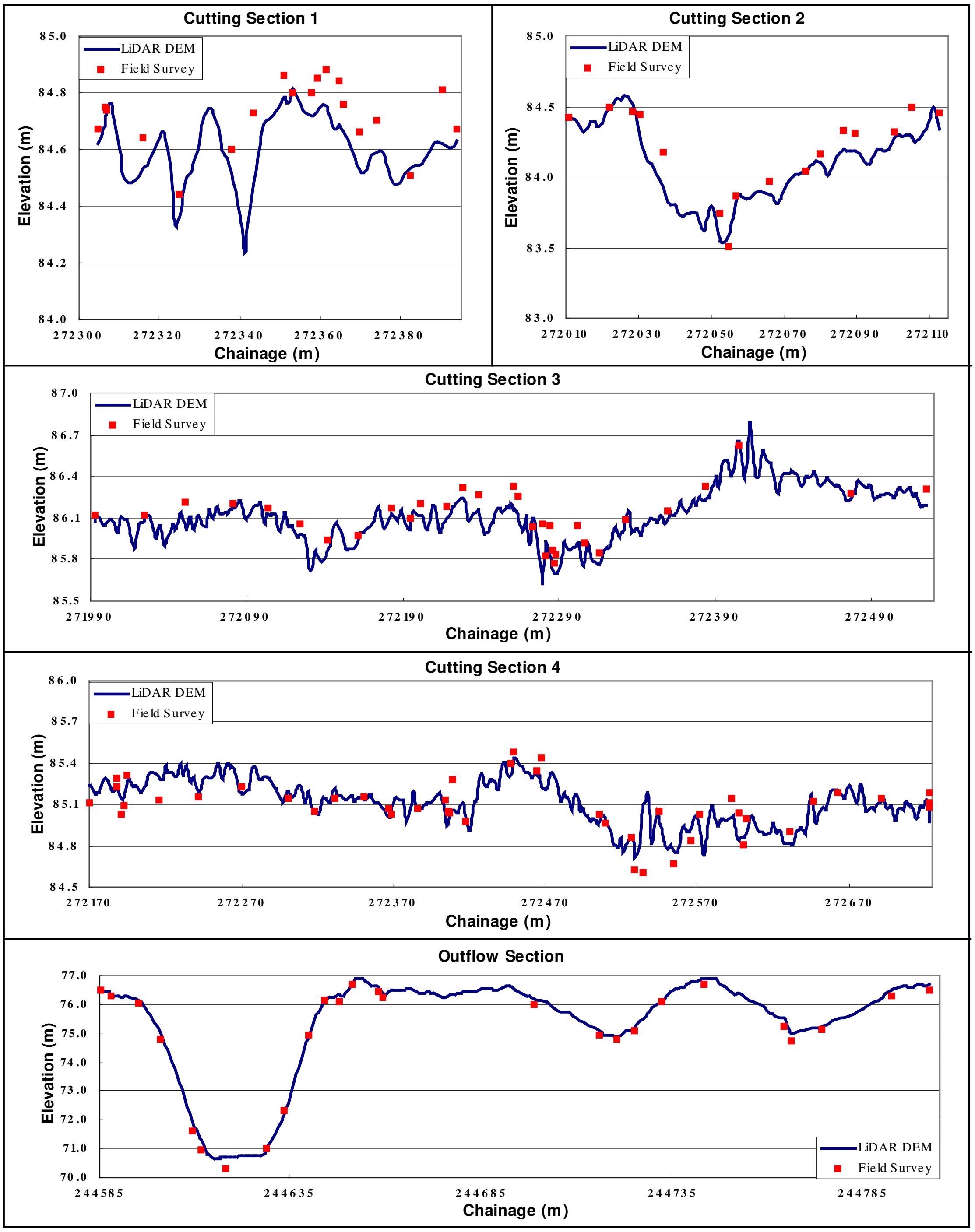

Figure 4 Cross-sections showing difference between Survey and LiDAR DEM derived elevations

Table 2 RMSE and Percentile comparison between survey and LiDAR derived elevations

Feature Survey Points	**LiDAR (1m DEM)**				
	Number of points used	Accuracy - RMSE Method (m)		Percentile Method (m)	
		68% confidence level	95% confidence level	68th percentile	95th percentile
Cutting	4836	0.1325	0.2597	0.1535	0.2903
Bullock Head Creek	208	0.15	0.2939	0.1719	0.3177
Inflow	366	0.3948	0.7737	0.3818	1.2812
Swan Lagoon	425	0.3187	0.6246	0.2776	1.0015
Outlet	447	0.2316	0.454	0.26	0.591
Levee	5378	0.414	0.8114	0.2703	1.4254