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# COMPARING NUTRIENT LOSS PREDICTIONS USING OVERSEER® AND STREAM WATER QUALITY IN A HILL COUNTRY SUB-CATCHMENT

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## Abstract

Hill country represents a significant proportion of New Zealand water catchment areas, particularly in the Manawatu region (75%), therefore, soil and nutrient management in pastoral hill country plays a vital role in the management and mitigation of water quality impacts. Improving our understanding of nutrient loss and nutrient attenuation in pastoral hill country will be essential in assisting beef and sheep farmers adapt to inevitable nutrient loss restrictions in the future.

We have established an on-going water quality study at Massey University's Tuapaka Agricultural Experimental Station, Palmerston North to monitor nutrient and sediment loads leaving an 85 ha sub-catchment. The sub-catchment incorporates both rolling and steep hill terrain, a number of seepage wetlands, and a range of different soil types. The monitoring results from Jun 2013 to Jun 2014 are presented in this paper. Further, detailed Overseer® nutrient budget modelling of this sub-catchment was undertaken to provide estimates of nitrogen (N) and phosphorus (P) losses to water and these values were compared with the nutrient loads estimated using the monitored stream flow and water quality. A comparison with historic (1976) nutrient loads measured from a larger catchment (180 ha) on the same farm, was also undertaken.

The current monitoring study showed that N, P and sediment concentrations leaving the sub-catchment were generally low, with elevated nitrate-N concentrations being measured in response to increased stream flow (as a result of surface runoff and drainage). Increased N, P and sediment concentrations appear to be linked to cattle grazing and fertiliser events. Total N (2.48 kg N/ha/year), total P (0.13 kg P/ha/year) and sediment (49 kg/ha/year) loads estimated to leave the sub-catchment were at the lower range of those previously measured by other NZ studies from generally smaller sub-catchments (<16 ha), grazed by beef and sheep. These loads were also lower than those modelled using an Overseer® nutrient budget (7 kg N/ha/year and 1.1 kg P/ha/year) for the sub-catchment. These differences could be explained by nutrient attenuation processes, as the sub-catchment contains natural features which enhance N and P attenuation, such as seepage wetlands, processes which may not be fully accounted for in the current version of Overseer®. However, climatic and farm management factors may also explain these differences, so it will be prudent to examine longer term data before any firm conclusions can be drawn. Nutrient and sediment loads were higher in the historic Tuapaka study (5.17 kg N/ha/year, 1.16 kg P/ha/year and sediment 1402 kg/ha/year), compared to the current study. The higher loads measured in the historic study can be explained by differing land use within parts of the larger sub-catchment, the sub-catchment including steeper soils more prone to erosion and possible climatic differences.

## Introduction

Hill country represents a significant proportion of New Zealand water catchment areas, particularly in the Manawatu region. Horizons Regional Council comprises the largest fraction of hill country (75%) of any council in New Zealand, with the majority of this land used for beef and sheep production. Beef and sheep grazing is the dominant land use (62%) in the Manawatu catchment. Although total sheep production has remained static, lambing percentage and growth rates have improved substantially over the last 20 years, due to improved animal management, genetics and increased feed availability and quality (Morris and Kenyon 2014). Research has also highlighted the potential live weight gains from producing bull beef, which capitalises on Friesian bull calves produced from the dairy industry (Morris and Kenyon 2014). In addition, the rapidly expanding dairy industry is increasingly utilising hill or rolling country for dairy support grazing. The use of alternative pasture species (Morris and Kenyon 2014), cropping in hill country and flat areas and increased nitrogen (N) fertiliser application, are likely to facilitate an increase in stocking rate and animal production in hill country.

Overlying this trend for intensification, is the New Zealand Ministry for Primary Industries' aim to double primary sector exports by 2025 whilst the Government's Business Growth Agenda aims to increase exports from 30 to 40% of GDP by 2025 (Ministry for Primary Industries 2013). Locally, the Manawatu-Whanganui Growth Study (Ministry for Primary Industries 2015), identified the improvement of on-farm productivity in hill country beef and sheep farming as a key priority for improving economic growth in the region.

Due to the large areas of land involved (241,108 ha above Palmerston North) (Parfitt *et al.* 2013), contributions of nutrients and sediments from hill country land use to the Manawatu river, are likely to be very important. Modelling using long-term average data suggest that beef and sheep grazing contributes ~45% of phosphorus (P) loads and ~89% of sediment loads measured at the Palmerston North monitoring site (Parfitt *et al.* 2013). Any intensification of the sheep and beef industry is likely to increase the risk of sediment and nutrient loss. It is likely that nutrient loss restrictions, already being applied to the more intensive dairy industry, will also apply to beef and sheep production in the near future. This highlights the need to improve our understanding of nutrient loss and attenuation processes in these environments and to validate the nutrient loss predictions in Overseer®, so that farmers and councils may better manage these issues in the future.

## Methods and materials

### *Water quality measurement and water balance*

A water quality monitoring study has been established on an 85 ha sub-catchment (Fig. 1) at Massey University's Tuapaka Agricultural Experiment Station, near Palmerston North. The farm is grazed with beef and sheep and normal farming operations continue throughout monitoring, including fertiliser and grazing events. Stream flows are monitored every 10 minutes using a 90° V-notch weir and a capacitance probe, to measure the water level. Stream water is sampled for suspended sediments, total N, nitrate-N, ammonium, total P and dissolved reactive P (DRP) every two weeks, with 8 additional samples collected opportunistically, during rising and falling flow conditions. On-site meteorological stations are installed to collect daily weather variables including rainfall, temperature, relative humidity, wind speed and solar radiation. Data collected from June 2013 to June 2014 are analysed and presented in this paper.

Nutrient loads were estimated using the flow stratified method recommended by a recent comparison of load calculation methods (Elwan *et al.* 2016). This method ranks stream flows into deciles and calculates loads using average nutrient and sediment concentrations associated with each decile. Usually, data is separated into 10 decile categories, but due to the spread of concentration data with respect to flow, 5 deciles were preferred in the current study to ensure that each flow decile was well populated with concentration data. Due to the seasonal pattern of nitrate concentration, it was important to compare the nitrate loads estimated using the flow stratified method to those estimated using the linear interpolation method. The linear interpolation method assumes a linear relationship between two concentration measurements and interpolates the nutrient load, based on flow rate, for the missing values in between. This method is similar to that used to calculate historic Tuapaka nutrient and sediment loads by Bargh (1978).

A daily soil water balance was calculated, where reference crop evaporation was estimated using the FAO56 version of the Penman-Monteith equation after incoming solar radiation had been adjusted for slope and aspect. It was assumed that all rainfall infiltrated the soil.

***Historic water quality study***

In 1975, Bargh (1978) monitored stream flow and water quality from an 180 ha sub-catchment (Fig. 1) on the same property (Tuapaka), for a period of one year. Water samples in the historic study were analysed for total P (TP), total dissolved P, nitrate-N, total N (TN) and suspended sediment (SS). Due to differences between the form of nutrients measured and laboratory methodologies, only TP, TN and SS are compared in this study. The weir used in Bargh's study was located further downstream on the flats and is currently in disrepair, so was not used as a monitoring site in the current study. The location of Bargh's monitoring site was such that it included any nutrient and sediment contributions from yard and shed areas and also included the steepest part of the catchment which was more prone to land slips. During Bargh's study period, 19 ha of the upper catchment was sown to a winter crop of swedes and Bargh (1976) noted that extensive erosion occurred as a result. In contrast, the sub-catchment monitored in the current study, did not include the shed or yard areas, which were likely to contribute nutrient rich runoff, and excluded the steepest part of the farm, prone to erosion. Both Bargh's (180 ha) and the current study (85 ha) sub-catchments included the 19 ha area sown to swedes during Bargh's study, however this area is now under pine forest, and has been so, for approximately 15 years.

***Overseer®***

An Overseer® 6.2.1 nutrient budget was undertaken on the sub-catchment area by creating management blocks to represent the different soil types and topographies within the study area. The sub-catchment area as a percentage of the whole farm, was used to estimate stock numbers grazing the sub-catchment. The sub-catchment included a seepage wetland with a catchment area of ~25ha and was included in the Overseer® budget, but had no impact on N or P losses.

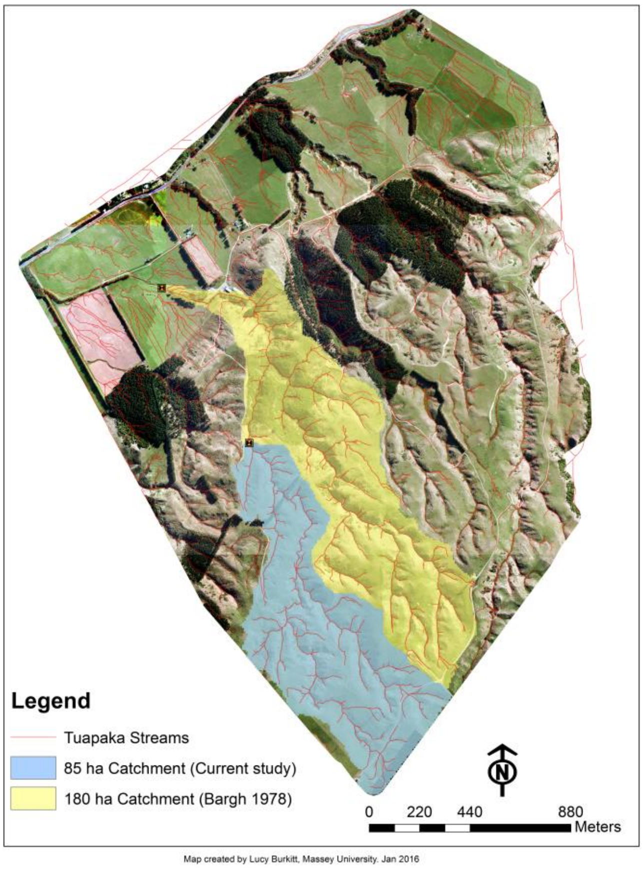


**Figure 1. Tuapaka farm showing the 85 ha sub-catchment monitored in the current study and the 180 ha sub-catchment historically monitored by Bargh (1978).**

## Results and discussion

### *Water balance*

The water balance (Table 1) estimates that on average about 68% of the rainfall received, contributed to the evapotranspiration and the remaining 32% of rainfall drained from the root zone, contributing to stream flow and/or groundwater recharge. About 26% of rainfall entered the stream and was measured at the weir. It is assumed that the difference (approximately 7% of the rainfall) percolated deeply through the soil and subsurface profile and did not enter the stream. The estimated cumulative drainage (Fig. 2) indicated that no drainage occurred between early November and early April in the sub-catchment, with drainage predicted to start in early April and continue through to late October. This drainage period corresponds with elevated nitrate concentrations measured in the stream leaving the sub-catchment (Fig 2a) and highlights that the high risk period for nitrate loss in hill country is consistent with our understanding of nitrate loss from flatter pasture systems, which have been more widely researched (Di and Cameron 2002).

The annual rainfall recorded at the site over the 2013-2014 monitoring period was 1030 mm which is similar to the long-term average annual rainfall (recorded on site) for the research farm of 1100 mm. The dry winter experienced in Palmerston North in 2013 (<80% of normal winter rainfall) (National Institute of Water and Atmosphere 2013) may have resulted in lower sediment and nutrient loads than usual, as winter is an important period for surface runoff and drainage of nitrate.

**Table 1. Water balance for the 85 ha sub-catchment at Massey University's Tuapaka Agricultural Experiment Station, near Palmerston North between June 2013 and June 2014.**

| Water Balance | Volume (mm) | % of rainfall |
|---|---|---|
| Total rainfall (mm) | 1033 | |
| Total evapotranspiration | 700 | 68 |
| Total drainage from root zone | 333 | 32 |
| Total volume measured at Main weir | 266 | 26 |
| Drainage minus weir volume | 69 | 7 |

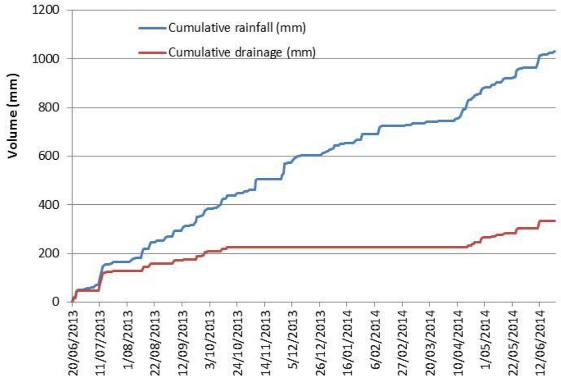


**Figure 2. A comparison of measured cumulative rainfall (mm) and estimated cumulative drainage (mm), based on the water balance, over the study period.**

***Water quality***

*Nitrogen*

Measured nitrate-N concentrations leaving the sub-catchment were generally low (<1 mg/L), often below the detection limit (0.25 mg/L) in the laboratory (Fig 3a). However, they were within the range measured by McColl *et al.* (1977) who reported mean nitrate-N concentrations of 0.07-0.09 mg/L (low flow) and 0.48-0.38 mg/L (high flow) in two small hill country pasture catchments (<5 ha) in the lower North Island. Elevated nitrate-N concentrations measured between autumn and late spring, corresponded to elevated stream flow in the current study ($r^2$ = 0.65, data not presented), probably caused by drainage and surface runoff. Christensen *et al.* (2012) reported nitrate-N loss in drainage decreased after sustained periods of drainage as the soil profile was depleted of nitrate-N. However, additional inputs of nitrate in the form of urine from grazing cows and urea fertiliser application in early Sep (Fig. 3a) may have extended the period of nitrate-N loss measured in the stream. Measured total N concentrations were generally <1.5 mg/L and followed a similar pattern to nitrate-N. Ammonium concentrations were negligible.

*Phosphorus and sediment*

Phosphorus concentrations leaving the monitored sub-catchment were low with TP generally <0.1 mg/L and DRP concentrations rarely reaching the laboratory detection limit (0.02 mg/L) (Fig. 3b), results which are consistent with McColl *et al.* (1977). Elevated DRP (0.07 mg/L) and TP (0.25 mg/L) concentrations were measured on 17 April 2014. This was the first elevated flow event following a long, dry period (Figs. 2 and 3), which may have resulted in hydrophobic soil conditions. In addition, surface runoff monitoring as part of an associated study, indicated that this was the first runoff event since the application of 125 kg/ha of single superphosphate, applied across the farm on 16 March, which may have increases P losses. Due to the water sampling strategy, it is not possible to accurately estimate the annual contribution this fertiliser may have had on P loads. Cooke (1988) reported that 20% of the annual P load could be attributed to the aerial application of P fertiliser in their 16 ha hill country catchment study, near Hamilton, NZ. In the current study, elevated P and suspended sediment concentrations tended to coincide with cows grazing in the sub-catchment (Fig. 3 b,c), however, longer term data are required before any relationship can be verified.

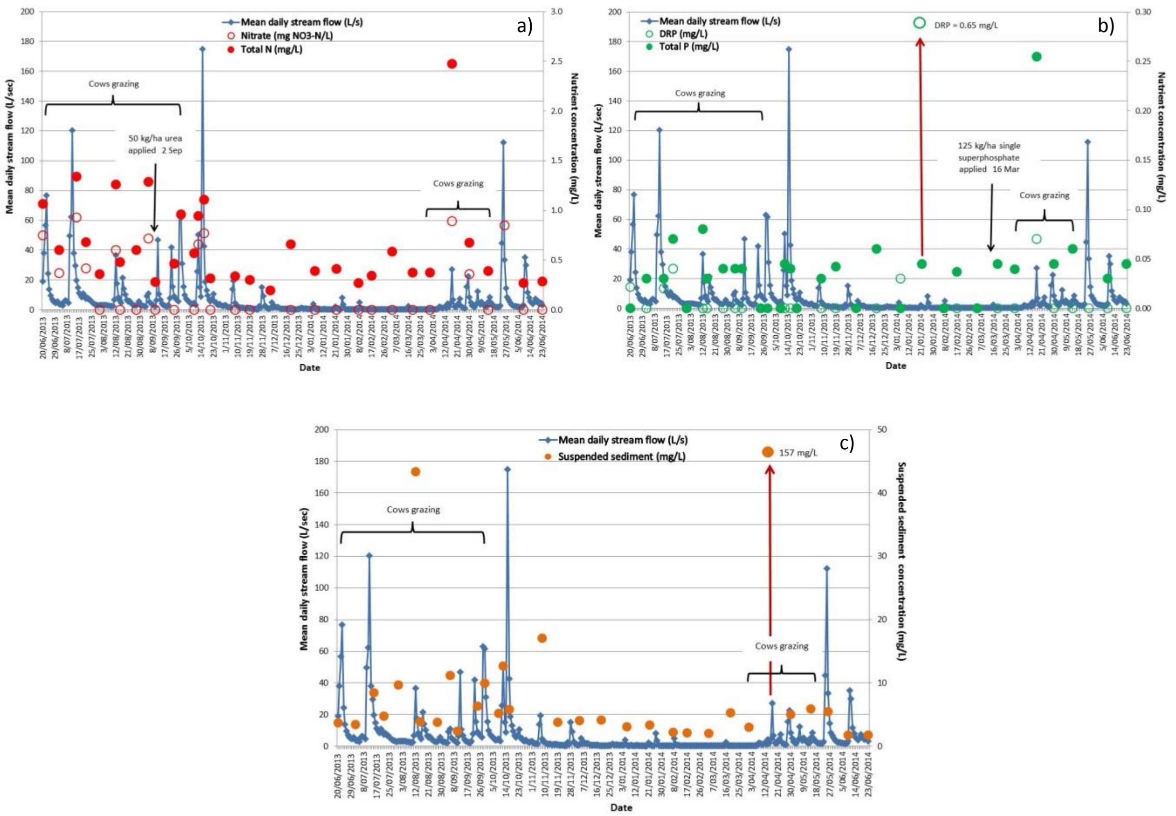


**Figure 3. Mean stream flow (L/s) and (a) nitrate-N and total N, (b) DRP and total P and (c) suspended sediment concentrations (mg/L) measured from the 85 ha sheep and beef grazed sub-catchment between June 2013 and June 2014.**

### *Nutrient loads*

Annual nutrient loads estimated in the current study using the flow stratified method (Table 2), are at the lower end of the ranges previously reported for total P (0.11-2.37 kg P/ha), total N (4-15 kg N/ha) and sediment (600-2000 kg/ha) from sheep and beef grazing catchments which were generally <16 ha (Cooke 1988; Cooke and Cooper 1988; Lambert *et al.* 1985; McDowell *et al.* 2008). On a per hectare basis, total N and P and suspended sediment loads measured in the current study were 48, 11 and 3.5% of those measured by Bargh (1976). Comparison of nutrient loads between catchments can be complicated by catchment size (larger catchments can increase the opportunity for attenuation), land-use and land management factors. The current study sub-catchment (85 ha) was almost half the size of the sub-catchment (180 ha) studied by Bargh (1976). Also, the upper part of their sub-catchment included 19 ha of winter swedes which resulted in extensive erosion (Bargh 1976). Additional nutrient loads in the historic study included runoff from the shed, feed pad and yard areas, as well as erosion from the steepest part of their sub-catchment.

The nitrate-N concentration measured using the linear interpolation method was similar to the load estimated using the flow stratified method (Table 2).

**Table 2. Nutrient and sediment loads (kg/ha/year) estimated from the 85 ha sub-catchment from June 2013-June 2014 using the flow stratified and linear interpolation methods, compared to historic loads estimated from the 180 ha sub-catchment on the same property in 1976.**

| Analyte | Load (kg/ha/year) | | |
|---|---|---|---|
| | 2013/2014 Flow stratified (5 deciles) | 2013/2014 Linear interpolation | Bargh (1976) Linear interpolation |
| Nitrate -N | 1.28 | 1.13 | |
| Total N | 2.48 | | 5.17 |
| Ammonium | 0.00 | | |
| Dissolved Reactive P | 0.04 | | |
| Total P | 0.13 | | 1.16 |
| Suspended sediment | 49 | | 1402 |

***Overseer® predictions***

The modelled N loss from the sub-catchment by Overseer® was 7 kg N/ha/year (Table 3), with the highest loss predicted from the well-drained Ramiha soil. This contrasts with lower N loads in the stream leaving this sub-catchment in the current study (2.48 kg N/ha/year) and in the historic study (5.17 kg N/ha/year) (Table 2) and suggests that the amount of N estimated to be leaving the root zone is reduced in the sub surface environment via attenuation before it reaches the stream. Based on the water balance, deep percolation was estimated to be 69 mm and total volume measured through the weir was 266 mm (Table 1). From this we can assume that approximately 0.64 kg N/ha may have percolated deeply through the soil and may have also been attenuated in the deep subsurface layers. In hill country landscapes, nitrate-N attenuation could also occur via denitrification in wetland and seep areas (Zaman *et al.* 2008) and within stream beds (Cooke and Cooper 1988). When stream losses are compared to modelled Overseer® losses, N attenuation rates are estimated at 0.65 (current study) and 0.26 (historic study) (Singh *et al.* 2014), and these N attenuation rates are within the range previously estimated within the Manawatu catchment (0.22 to 0.73) (Singh *et al.* 2014).

**Table 3. Overseer® N loss table for the 85 ha sub-catchment grazed by beef and sheep at Tuapaka, Palmerston North from Jun 2013 to Jun 2014.**

| Block name | Total N lost<br>kg N/yr | N lost to water<br>kg N/ha/yr | N in drainage *<br>ppm | N surplus<br>kg N/ha/yr | Added N **<br>kg N/ha/yr |
|---|---|---|---|---|---|
| Korokoro | 53 | 8 | N/A | 63 | 23 |
| Ramiha | 126 | 9 | 2.5 | 75 | 23 |
| Makara steepland | 218 | 6 | N/A | 61 | 23 |
| Shannon | 23 | 8 | 2.1 | 69 | 23 |
| Other sources | 11 | | | | |
| Whole farm | 431 | 7 | | | |
| Less N removed in wetland | 10 | | | | |
| Farm output | 421 | 7 | | | |

Phosphorus loss risk varied with soil type, slope, Olsen P and relative stocking rate, with P loss risk highest on the imperfectly drained, low anion storage capacity Shannon soil. Estimated Overseer® P loss for the sub-catchment was 1.1 kg P/ha/year (Table 4) compared to the P load leaving the sub-catchment in the current study (0.13 kg P/ha/year). This represents a P attenuation rate of 0.88. This attenuation factor is comparable to the 0.80 attenuation factor calculated between the Manawatu catchment area and the Manawatu river by Parfitt *et al.* (2013). Like N, P can also be attenuated within sub-catchments via landscape features such as wetlands which potentially trap sediment and slow water flow, allowing P to potentially be absorbed by plants and adsorbed by sediment in stream beds and banks. In contrast, P losses from the 180 ha sub-catchment, were similar to those predicted by Overseer® (Tables 2 and 4).

**Table 4. Overseer® P loss table for the 85 ha sub-catchment grazed by beef and sheep at Tuapaka, Palmerston North from Jun 2013 to Jun 2014. Additional data on block slope, soil Olsen P and (relative stocking unit) RSU/block has been added to aid interpretation.**

| Block name | Total P lost | P lost to water | | P loss categories | Slope | Olsen P | RSU/block |
|---|---|---|---|---|---|---|---|
| | kg P/yr | kg P/ha/yr | Soil | Fertiliser | | | |
| Korokoro | 5 | 0.7 | Low | Low | Easy hill | 25 | 9 |
| Ramiha | 4 | 0.3 | Low | Low | Rolling | 28 | 11 |
| Makara steepland | 51 | 1.4 | Medium | High ** | Steep | 22 | 8 |
| Shannon | 5 | 1.7 | High | Medium | Rolling | 25 | 10 |
| Other sources | 5 | | | | | | |
| Whole farm | 69 | 1.1 | | | | | |

## Conclusion

This paper provides insights in to the nutrient and sediment loss processes that are occurring in NZ hill country landscapes, presenting a case study of an 85 ha sub-catchment draining the Tuapaka farm in the Manawatu River catchment. Although estimated stream nutrient loads leaving the sub-catchment were much lower than those predicted to leave the root zone using Overseer®, it is likely that nutrient attenuation processes occurring in the sub surface and within wetlands and wet areas, may explain some of these differences. Indeed, attenuation rates estimated from the current study are within the range previously estimated for the Manawatu catchment. However, longer term data are required before any conclusive comparisons can be made. A comparison of nutrient and sediment loads on a per hectare basis between the current monitoring study and Bargh's historic study found that N, P and sediment losses were much lower in the current study. These differences are likely due to higher rates of erosion and nutrient inputs in the historic study, due to farm management and landscape features that were encompassed in the larger sub-catchment area.

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