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Examination of Differences in Water Quality and Quantity by Reservoir Catchment with a Different Land-Use Type in the Republic of Mauritius

Fatema Nabybaccus [1], Don Koo Lee [1], Yohan Lee [2,*] and Jung Il Seo [3,*]

[1] Department of Sustainable Development, Park Chung Hee School of Policy and Saemaul, Yeungnam University, 280 Daehak-ro, Gyeongsan-si, Gyeongsangbuk-do 38541, Korea; fnabybaccus@gmail.com (F.N.); donkoolee@ynu.ac.kr (D.K.L.)

[2] Department of Forest Resources and Landscape Architecture, College of Life and Applied Sciences, Yeungnam University, 280 Daehak-ro, Gyeongsan-si, Gyeongsangbuk-do 38541, Korea

[3] Department of Forest Resources, College of Industrial Sciences, Kongju National University, 54 Daehak-ro, Yesan-gun, Chungcheongnam-do 32439, Korea

* Correspondence: johnlee@yu.ac.kr (Y.L.); jungil.seo@kongju.ac.kr (J.I.S.); Tel.: +82-53-810-2922 (Y.L.); +82-41-330-1302 (J.I.S.)

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Abstract: Forest buffers contribute to enhancing the quality and availability of water in catchments. This study aims to examine the effects of forest buffers on water quality and quantity in three reservoir catchments in Mauritius, including Mare aux Vacoas (MAV), Mare Longue (ML), and La Ferme (LF). While MAV and ML are surrounded by forests, the forested area of LF was cleared for photovoltaic panels for electricity generation and agriculture. We used catchment simulation modeling and empirical data analysis. The results showed that the concentrations of water quality parameters, such as conductivity, silica, total suspended solid (TSS), total organic carbon (TOC), NO_3^-, NO_2^-, and total reactive P in LF were higher than those in MAV and ML. Sparsely vegetated lands can lead to water quality degradation due to surface runoff. In addition, the water quantity per unit area for MAV and ML were greater than that for LF, which indicated that a high percentage of forest buffer cover also positively influences the quantity of water in catchments. Our findings suggest that forest buffers have a critical importance in hydrological cycles and also enhance water production, and thus should help develop an effective and innovative water resource management strategy in Mauritius.

Keywords: forest buffer; catchment; runoff; water quality; water quantity; Mauritius

1. Introduction

Forest buffers are vegetated areas with grasses and trees around water resources in catchments, which protect them from non-point source pollution, stabilize their banks, and reduce soil erosion [1]. Forest buffers play an important role in attenuating flooding and landslides, thereby minimizing sedimentation and siltation from runoff. Previous studies have shown that forest buffers around the periphery of the waterway are important for the conservation of limited water resources. According to Calder et al. [2], forest buffers act as a ground cover for drinking water and reduce or eliminate pollutants of industrial and agricultural origin by acting as natural biofilters against sediments and pollutants along water courses. The availability and quality of water is strongly influenced by forests, but the role of forests can be hampered due to high rates of deforestation, especially in developing regions, which also threatens water resource management [1]. Bergkamp et al. [3] argued that climate change is altering forest roles in regulating water flows and influencing the availability of water resources. It is postulated that in 2025, the world will face an unprecedented cataclysm due to an imminent water crisis. The FAO [4] forecasted that millions of people worldwide would be subjected to absolute water scarcity, while the vast remainder would be subjected to water stress. The expected water resource crisis may not only affect rain-fed and irrigated agriculture, but also exacerbate changes in water regimes and the availability of freshwater [5]. In order to address the water resource crisis, it is critical to mitigate deforestation, which undermines the environment's capacity to provide ecosystem services, and in particular, clean water [6].

In Mauritius, the total forest area, corresponding to about 25% of the total land area, has declined by 5 ha from 47,108 ha in 2013 to 47,103 ha in 2014. Also, the net carbon dioxide (CO_2) emissions have increased by 2.6% from 2012 to 2013 (Statistics Mauritius, 2014). Deforestation and forest degradation contribute to atmospheric greenhouse gas (GHG) emissions through both combustion and decomposition. A literature review shows that GHG emissions positively contribute to global warming and climate change. The emerging phenomenon of climate change, which is a serious environmental issue, coupled with increasing population puts Mauritius at risk on both national and global platforms. The freshwater reserves in Mauritius are particularly of concern because of increasing water demands resulting in the perpetual anthropogenic degradation of water.

Residents in the central districts of Mauritius obtain their domestic water supplies from Mare aux Vacoas (MAV) reservoir, which is the largest potable water source in Mauritius. Over the past two decades, some parts of the state-forested land areas around the MAV reservoir have been cleared for the introduction of agriculture. A rough approximation using Google Earth satellite images showed that the patches of forest buffers, ranging from 40 m to 200 m in width, are present within the transition regions separating the agricultural areas from MAV. Since agricultural practices involve soil structure modifications and disturbances through tillage practices and the use of chemicals, these activities could impinge on the water quality of MAV.

Although the MAV reservoir is favorable to high precipitation, high surface runoff could result in a contaminated sediment washoff, which could degrade the water quality of the MAV reservoir. One of the least noticeable impacts is the bioaccumulation of pesticides in the reservoir organisms and ecosystem. The intensive practice of inorganic farming around the reservoir area may contribute to the pollution of the environment through the leaching of nitrate to groundwater [7]. While the import of fertilizers increased by 16.0%, from 45,924 tons to 53,276 tons, and that of pesticides increased by 0.7%, from 2185 tons to 2201 tons from 2013 to 2014, the concern for further water contamination is omnipresent.

Several researchers have attempted to elucidate the relationship between forest buffers and water quality in given catchments in countries such as the Philippines, Japan, and Kenya. For example, Dessie and Bredemeier [8] investigated the effect of deforestation on water quality based on physicochemical properties, and evaluated the community-based water resource management schemes in the Philippines. They found that the physical properties (as opposed to chemical properties) of the deforested regions were altered compared with those of the forested area. Also, Trancoso et al. [9] argued that conserving natural vegetation cover is critical for maintaining the ecological integrity and hydrological properties of large river catchments in the Brazilian Amazon. The land use and cover change (LUCC) in major catchments was analyzed to evaluate the current balance between the deforestation and conservation of natural areas in the region. Their results showed that in regions with critical levels of deforestation, more than 80% of the subcatchments had been affected.

Furthermore, Masese et al. [10] combined the effects of land use, physicochemical indicators, and resident aquatic biota indicators to determine changes in the surface water quality in the Lake Victoria Basin, Kenya. They found that the increased intensity of agriculture and deforestation in the region influenced the magnitude and frequency of runoff events, and increased pesticide contamination, erosion, and sedimentation in streams and rivers. Singh and Mishra [11] found possible correlations between forest cover, water quality, and treatment costs by investigating how the drinking water was impacted by deforestation within catchments, which emphasized the urgent need to protect and conserve water resources, especially with the advent of climate change.

However, in Mauritius, no study to date has attempted to investigate the impact of forest buffers on water resource management.

The objective of this study was to examine the effects of forest buffers on water quality and quantity in the MAV reservoir, Mauritius. In particular, we focus on investigating the effect of land-use change on water quality and quantity by comparing the current status of water quality and quantity of three watersheds in Mauritius. We believe that this study may help the government develop an effective and innovative water resource management strategy that encompasses both proper scientific planning and conservation policies to address deforestation and enhance the availability of clean water in the catchments.

2. Materials and Methods

2.1. Study Site Description

This study was conducted in three locations in Mauritius, including the MAV, Mare Longue (ML), and La Ferme (LF) reservoirs (Figure 1), although our main focus was on the forest buffers around the MAV reservoir. We processed the spatial information related to LUCC catchment areas around those reservoirs. The catchment areas, including the MAV, ML, and LF reservoirs, as well as their surrounding areas, were mapped using ArcGIS 10.2 (ESRI, Redlands, CA, USA). Buffers occupying the size of the catchment area of each reservoir were delineated in order to estimate the coverage areas of land-use types falling within their respective buffer zones (Table 1). In this study, due to limited access on the information of those catchments, we extracted the catchment area buffered with a 1.0-km radius from each reservoir boundary, and postulated it as the area of each study. The MAV and ML catchments have good quality forests that cover 11 km^2 and 5 km^2, respectively, thereby protecting them from pollution and soil erosion, compared with the forests in the LF catchment, which cover 3.17 km^2. The Geographic Information System (GIS) data revealed that some forest areas within these catchments have been converted to other land uses, such as agriculture and road networks.

Table 1. Land-use types, catchment areas, and forest buffers of each study reservoir catchment. MAV: Mare aux Vacoas reservoir, ML: Mare Longue reservoir, and LF: La Ferme reservoir.

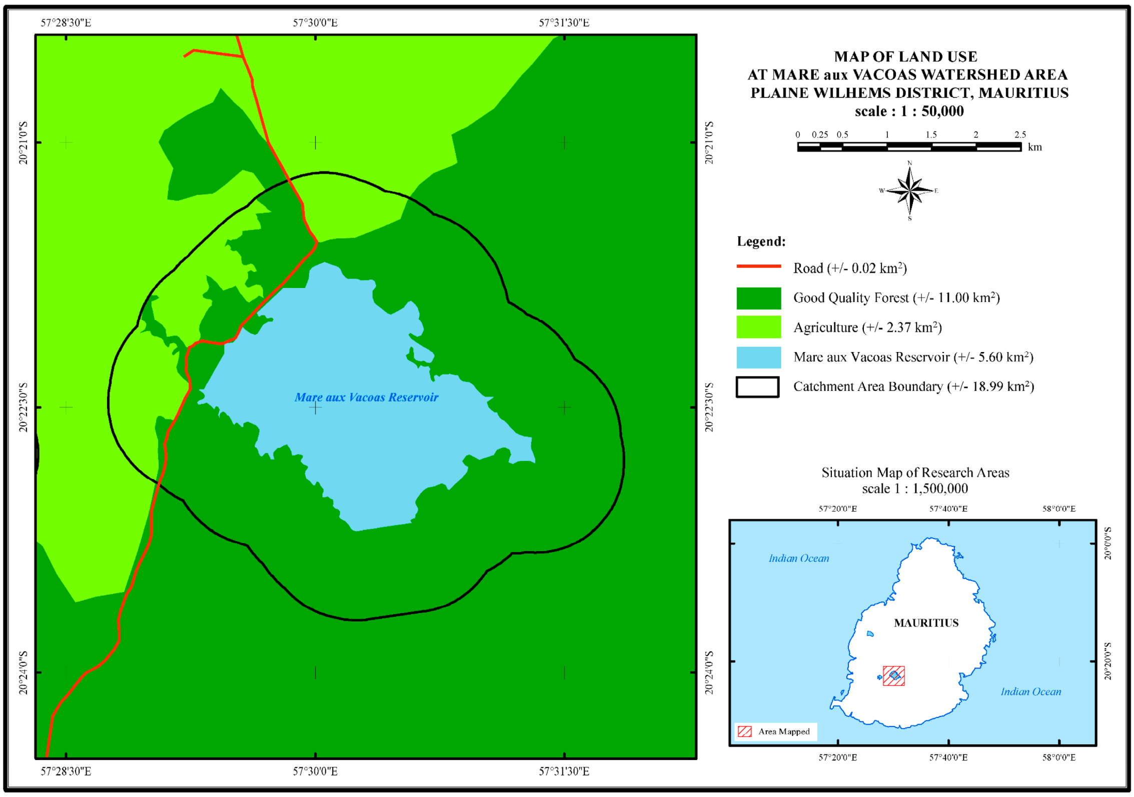
Reservoir Name	Land-Use Types	Area (km^2)	Total Catchment Area (km^2)	Forest Buffer Coverage (%)
MAV	Good quality forests	11.00	19.50	58
	Agriculture	2.37		
	Roads	0.02		
	Reservoir area	5.60		
ML	Good quality forests	5.00	6.45	78
	Agriculture	0.40		
	Reservoir area	1.05		
LF	Good quality forests	3.17	19.60	30
	Bad quality forests	2.70		
	Agriculture	7.71		
	Photovoltaic panels	0.27		
	Settlement	3.46		
	Reservoir area	2.28		

The MAV reservoir is the largest one in Mauritius, and was built in 1885. The MAV reservoir is located in the Central Plateau, which is a superhumid zone in the Plaine Wilhems district that is approximately 566.35 m above sea level, and has an estimated gross storage capacity of 25.89 million m^3, providing an annual yield of 33 million m^3 used solely as domestic water supply to residents in the district [12]. The catchment area of MAV is 19.50 km^2, with a maximum water spread area of about 5.6 km^2, which is supplied by six feeder canals. The local reservoir catchment receives an estimated inflow contribution of 14 million m^3 annually [13]. The mean annual precipitation in the catchment area is approximately 3300 mm.

In addition, the ML reservoir is located in the central plateau of the Plaine Wilhems district, at an elevation of 576.91 m above sea level. The ML reservoir was built in 1948 for the purposes of hydroelectric power generation and irrigation [12]. Supplied by three feeder canals, ML occupies a catchment area of 6.53 km^2 with a reservoir capacity of 6.28 million m^3, which occupies a surface area water spread of 1.05 km^2. The reservoir receives mean annual precipitation of 2980 mm and is mostly surrounded by good quality forests. ML and MAV share similar land-use characteristics, and are approximately 2.5 km apart.

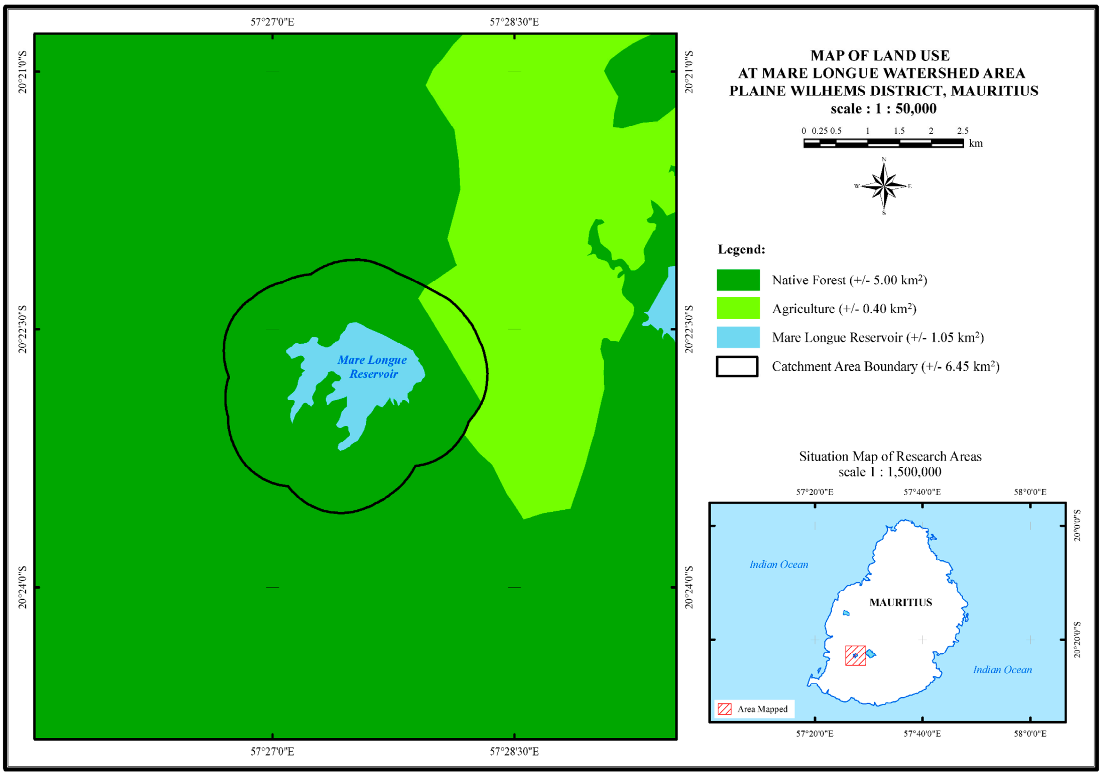
The LF reservoir was built for the purpose of irrigation in 1914. The LF reservoir is located on the western coast of Mauritius at 146.0 m above sea level in the district of Black River. LF occupies a catchment area of 19.61 km^2 with a reservoir capacity of 11.52 million m^3. LF occupies a maximum water spread area of 2.28 km^2, and is supplied by two feeder canals. LF suffers a hot and dry climate, and receives a mean annual precipitation of 1380 mm [12]. The main land uses consist of poor agricultural lands and settlements. Its surrounding areas have sparse good quality forests, as well as some poor quality forest buffers along the perimeters.

All of the vegetation areas around these reservoirs have undergone land-use changes. In particular, some forested areas around the LF reservoir were cleared for photovoltaic panels for electricity generation and agriculture. Due to the various land-use changes, LF reservoir was used as the negative control for water quality and quantity. However, MAV and ML reservoirs are still surrounded by native forests, and hence were used as the positive controls for water quality and quantity.

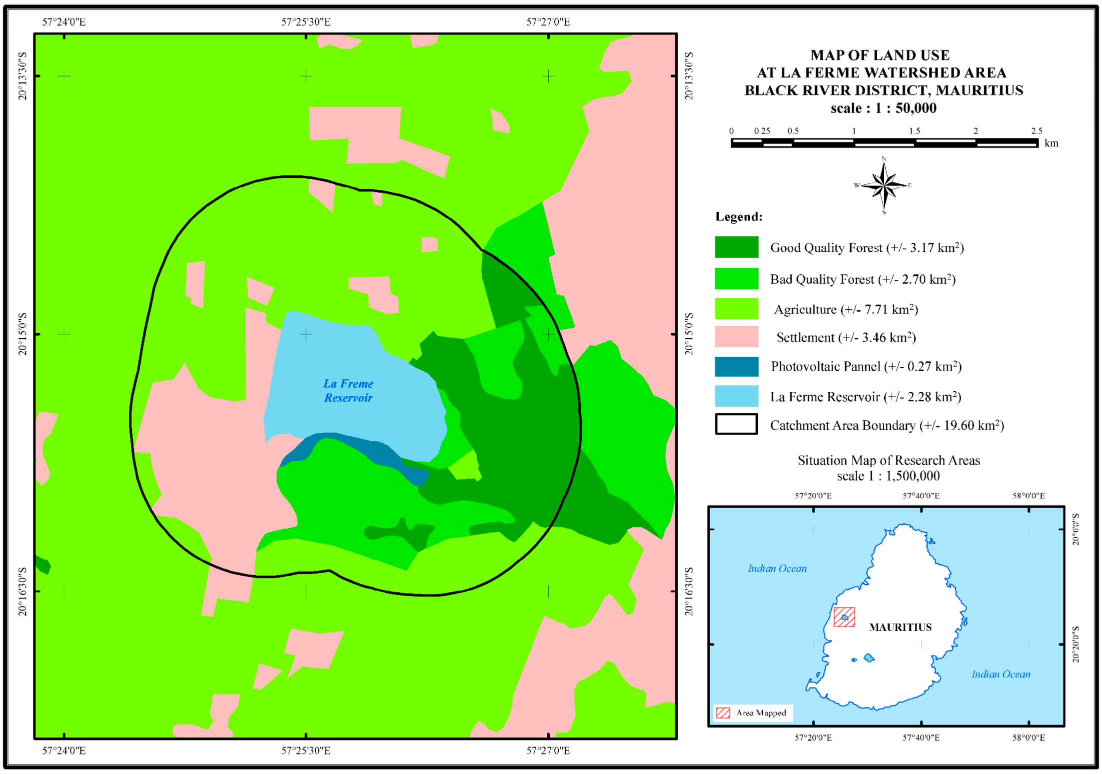


(**a**) Land-use conditions around the MAV reservoir.

Figure 1. *Cont.*



(**b**) Land-use conditions around the ML reservoir.



(**c**) Land-use conditions around the LF reservoir.

Figure 1. Map of land use in the catchment areas of (**a**) MAV, (**b**) ML, and (**c**) LF reservoirs.

2.2. Data Collection and Model Specification

This study used secondary data to highlight the importance of forest buffers in the conservation of water quality and quantity in the catchment area of the MAV reservoir in Mauritius. The physicochemical parameters shown in Table 2, which reflect the water quality of the MAV reservoir with respect to two control points (i.e., ML (positive control) and LF (negative control) reservoirs), were obtained from the Central Water Authority (CWA) and analyzed using SPSS. The CWA is a semi-governmental institution that monitors raw and treated water sources and supplies across the island. Its mission is to secure and provide a sustainable water supply service of appropriate quality to the increasing population. The data from the CWA is reliable because its laboratory is ISO 17025:2005(E) accredited. Algae, pesticides, heavy metals, physicochemical, and microbiological tests are routinely performed on water samples, and the analytical results have to be compliant with the World Health Organization (WHO) norms and the Mauritian Drinking Water Standards of the Ministry of Environment. According to the Annual Report 2014, the CWA has growing concern about climate change, which has caused fluctuations in the intensity and spatial distribution of the mean annual precipitation, which is greatly affecting water availability.

Table 2. Water monitoring information for each catchment area.

Reservoir Name	MAV	ML	LF
Monitoring/sampling sites	La Marie	Mare Longue	Trianon-Grosse Roche LF spillway Pierrefonds
Sampling exercise	63	10	103
Sampling period	March 2010–January 2016	October 2014–November 2015	January 2010–January 2016
Parameters monitored in MAV and LF	Color, Salinity, Total Dissolved Solids (TDS), Sulphate (SO_4^{2-}), Chloride (Cl^-), Chemical Oxygen Demand (COD), Acidity, Total Alkalinity, Total Hardness, Calcium (Ca) and Magnesium (Mg) Hardness, Carbonate (CO_3^{2-}) and Non-carbonate Hardness, Ca and Mg		
Parameters monitored in all three reservoirs	pH, Turbidity, Total Organic Carbon (TOC), Total Suspended Solids (TSS), Ammonia Nitrogen (NH_3-N), Nitrate as N (NO_3^--N), Nitrite as N (NO_2^--N), Silica and Total Reactive Phosphorous as P		

2.3. Model Parameters

2.3.1. Inherent Water Quality Characteristics in Each Reservoir

The multiple regression model was used to analyze whether the physicochemical parameters of each reservoir exhibited any possible intercorrelation. This model can generate pairwise correlations among all of the water quality variables, including intercorrelations among the independent variables and correlations with the dependent variable [14]. The data from each reservoir was modified and transformed to logarithmic scale in order to make the distribution less skewed, make patterns more visible, stabilize the variances, remove the outliers, and ease interpretation [15]. Since a linear regression model was used, a linear relationship and normal distribution were assumed between any intercorrelated variables. For MAV and LF reservoirs, the parameters of TOC, carbonate and non-carbonate hardness, TSS, silica, acidity, and total alkalinity were excluded from the regression model. This was done to standardize the time frame of the monitoring period (March 2010 to January 2016). The statistical significance of the relationship between the variables was determined using a 95% level of confidence or p-value less than or equal to 0.05.

2.3.2. Determination of Surface Runoff Using the Curve Number Method

The curve number (CN) method helps to predict direct surface runoff in catchments from a 24-h rainfall event. The determination of the CN depends on the soil groups, cover type, treatment/conservation practices, hydrological conditions, and topography. Once these factors are established, the corresponding CN can be selected from the CN table. A higher CN value indicates higher runoff, and the value ranges from 0 to 100 [16].

The total weighted CN value was computed from the area of the land-use types in the catchment, and was determined as follows (Equation (1)):

$$S = \left(\frac{25,400}{CN_{wt}} - 254\right) \quad (1)$$

where S is the maximum potential difference between rainfall and runoff in mm, and CN_{wt} is the weighted CN.

The direct surface runoff depth (Q) in mm was determined by entering the corresponding daily precipitation depth, as shown in Equation (2). Here, I represents the daily precipitation depth in mm. Also, the annual runoff depth Q_a was calculated by adding all of the Q values (Equation 3). Finally, the annual runoff from the catchment area was calculated using Equation 4.

$$Q = (I - 0.2S)^2/(I + 0.8S) \quad (2)$$

$$\text{Annual runoff depth}: \ Q_a = \sum Q \quad (3)$$

$$\text{Annual runoff from catchment area (mm/year)} = Q_a \times \text{Catchment area (km)}^2 \quad (4)$$

According to Statistics Mauritius [7], a decrease of 1.5% in the mean annual precipitation from 2013–2014 was observed. Hence, the mean precipitation in the study catchments was modified accordingly. Daily precipitation data were gathered from MeteoMauritius, Silvio's Convivium, North District of Mauritius, and then modified to acquire the mean monthly precipitation of 2014 in each catchment.

2.3.3. Determination of Water Quantity Using the Water Balance Equation

Using the calculations of the water influx and yield for each reservoir, we attempted to determine whether forest buffers around the reservoirs affected the water quantity. The water balance equation was used to describe the movement of water in and out of a system; the equation is as follows:

$$\Delta S = (AP + GW_{in} + Q_{in}) - (ET + GW_{out} + Q_{out}) \quad (5)$$

where ΔS is the change in storage; AP is the annual precipitation into the reservoir; GW_{in} is the groundwater influx; Q_{in} is the runoff influx; ET is the evapotranspiration; GW_{out} is the groundwater outflux; and Q_{out} is the runoff or discharge outflux. Here, we first obtained general information of water balance of whole Mauritius estimated by precipitation data for 2013–2014 from Statistics Mauritius [7]. We then applied the annual precipitation at reservoir sites to the obtained water balance in order to estimate Q_{in}, Q_{out}, GW_{in}, and GW_{out} for each reservoir. All of the units are in Mm^3.

$$\text{Annual water influx per unit area (m)} = (GW_{in} + Q_{in})\text{Mm}^3/\text{Catchment area}\left(\text{km}^2\right) \quad (6)$$

$$\text{Annual water yield per unit area (m)} = (GW_{out} + Q_{out})\text{Mm}^3/\text{Catchment area}\left(\text{km}^2\right) \quad (7)$$

3. Results and Discussion

3.1. Comparison of Water Quality among Reservoir Catchments

The results showed their mean and standard deviation of the following water quality parameters: pH, conductivity, TSS, TOC, $NO_3{}^-$-N, silica, and total reactive P. Those values of LF, a negative control, are higher than those of MAV and ML, the positive controls, as shown in Table 3. In addition, the results of two sample *t*-tests showed that there is a significant difference in the physicochemical parameters such as pH, conductivity, TSS, $NO_3{}^-$-N, total reactive P, silica between MAV and LF, and conductivity, turbidity, TSS, TOC, NH_3-N, $NO_3{}^-$-N, total reactive P, and silica between LF and ML.

Conductivity, TSS, TOC, and silica are indicators of soil erosion and sedimentation runoffs occurrence in various physiochemical conditions, and there are usually positive correlations among them [17–19]. Also, the presence of nitrates, nitrites, and phosphates usually indicate domestic and agricultural runoffs or even sewage contamination [20,21]. Unexpectedly, higher mean values were detected for the turbidity and NH_3-N in the ML reservoir. Thus, except for turbidity and NH_3-N, the MAV and ML catchments where surrounded by well-preserved native forest mostly indicate lower magnitudes of physicochemical parameters, compared with the negative control of the LF catchment, where the has forest cleared partially for electricity generation and agriculture, as well as poor-quality forest buffers (Figure 2).

Table 3. Mean (M), standard deviation (SD), and two sample *t*-test results of physicochemical parameters in the Mare aux Vacoas (MAV), Mare Longue (ML), and La Ferme (LF) reservoirs.

Parameters	MAV		LF		ML		Two Sample *t*-Test	
							MAV vs. LF	LF vs. ML
	M	SD	M	SD	M	SD	(*t*-Value)	(*t*-Value)
pH	6.99	0.47	7.63	0.64	7.61	0.73	−5.87 *	0.87
Conductivity	59.56	8.1	318.86	37.97	61.44	5.66	−50.54 *	20.13 *
Turbidity	4.28	2.16	5.33	4.56	12.7	12.18	−1.54	−3.11 *
TSS	2.41	2.49	9.26	8.3	2.56	4.9	−3.78 *	2.25 *
TOC, mg/L	2.38	1.48	9.78	16.21	4.82	2.98	−1.89	0.79
NH_3-N, mg/L	0.04	0.04	0.03	0.03	0.09	0.08	0.52	−3.76 *
NO_3^--N, mg/L	0.26	0.32	4.5	2.46	0.09	0.15	−13.06 *	5.31 *
NO_2^--N, mg/L	0.006	0.011	0.008	0.007	0.004	0.002	−0.72	1.63
Total reactive P, mg/L	0.08	0.06	0.15	0.08	0.07	0.04	−4.94 *	2.96 *
Silica, mg/L	1.67	1.53	15.56	5.48	3.86	2.21	−11.37 *	6.10 *

* $p < 0.05$.

In addition, higher mean values of other physicochemical parameters, such as TDS, salinity, SO_4^{2-}, Cl^-, total alkalinity, hardness, acidity, and color, were detected for LF compared with MAV (Table 4). Usually, TDS, salinity, SO_4^{2-} and Cl^- indicate dissolved salts and the ionic balance of the waters [22–24]; these parameters in LF may be affected by the runoff of various types of non-point source contaminants derived from forest buffers with poor conditions, agricultural lands, and other land uses. Also, alkalinity and hardness can positively influence upon an increase in pH values [25,26] and this should be the reason why the following phenomena occur. Interestingly enough, the mean pH value of LF with poor conditions of forest buffers falls in the alkaline spectrum, whereas it of MAV with well-preserved native forests ranges from mostly acidic to neutral (Table 3). Especially, alkalinity is increased by eutrophication, with high rates of algal photosynthesis and consumption of CO_2 [27–29], and thus could be indirect criterion that evaluate the degrees of both eutrophication in LF or soft water property, and are conducive to establish drinking water standards in Mauritius. Color indicates the presence of colored compounds released from decomposing organic matter [30,31], and the results showed that a larger amount of organic matter in the LF catchment with partially cleared forest was flowed into the reservoir, compared with the MAV catchment.

The overall results clearly indicated the lower water quality of LF than that of MAV (Figure 3), which contains various land-use types comprising of 30% of forest buffers. Hence, it can be argued that low vegetation coverage and intensive land uses in the LF catchment are critical elements that triggered water quality degradation. Other factors such as regular erosion and runoff events are also responsible for leaching pollutants, nutrients, and sediments to the reservoir.

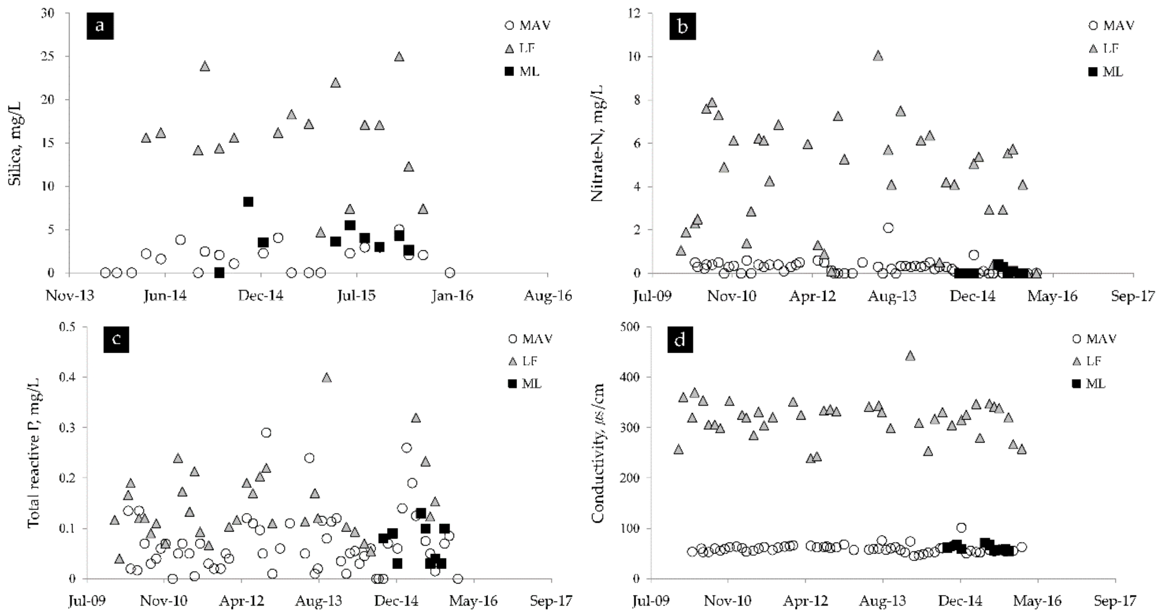


Figure 2. (**a**) Silica, (**b**) nitrate-N, (**c**) total reactive P, and (**d**) conductivity trends in the Mare aux Vacoas (MAV), Mare Longue (ML), and La Ferme (LF) reservoirs.

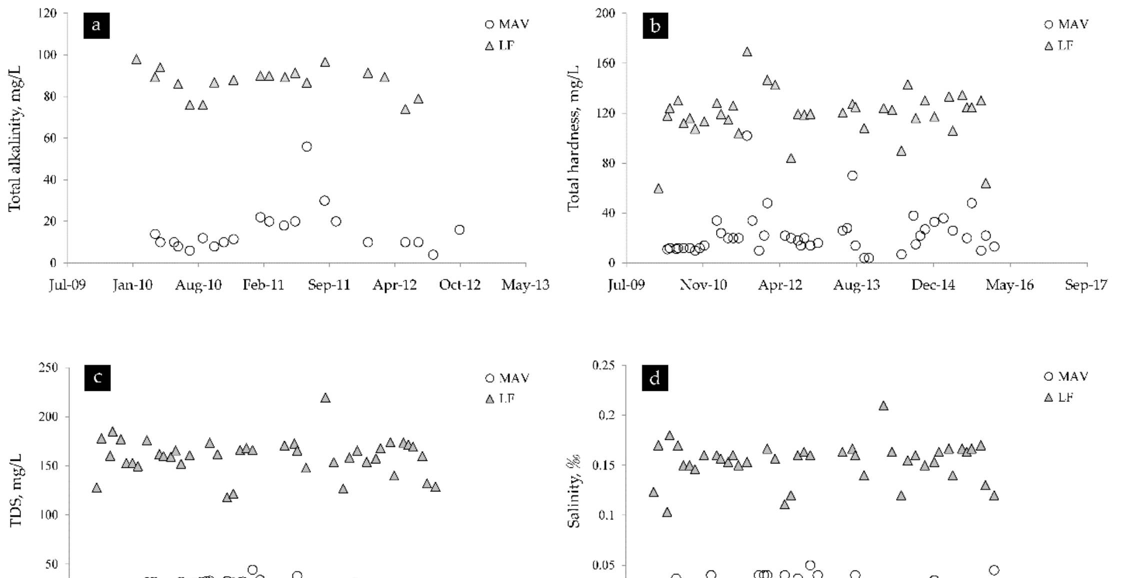


Figure 3. (**a**) Total alkalinity, (**b**) total hardness, (**c**) TDS, and (**d**) salinity trends in the Mare aux Vacoas (MAV) and La Ferme (LF) reservoirs.

Table 4. Ranges and mean values of physicochemical parameters in the Mare aux Vacoas (MAV) and La Ferme (LF) reservoirs.

Parameters	MAV		LF	
	Range	Mean	Range	Mean
TDS, mg/L	10–44	26.4	118–219	159.6
Color, Pt/Co	0–62	25	0–254	95
COD, mg/L	1.3–29	7.8	3–29	6.8
Salinity, %■	0.010–0.115	0.029	0.103–0.210	0.154
SO_4^{2-}, mg/L	0.7–10.0	2.2	5.0–21.7	16.9
Cl^-, mg/L	4.3–18.8	10.4	17.0–28.7	25.2
Total alkalinity, mg/L	4–56	16	74–98	87
Acidity, mg/L	0–6	3.0	0–10	4.6
Total hardness, mg/L	4–102	23	60–170	119
Ca hardness, mg/L	2–60	10.8	24–68.7	57.0
Mg hardness, mg/L	1.3–92	15.5	4–110.7	63.6
CO_3^{2-} hardness, mg/L	6–22	13.2	30–94	82.6
Non-CO_3^{2-} hardness, mg/L	0–36	5	17.3–44	30.3
Ca^{2+}, mg/L	0.8–20	3.8	9.6–27.3	22.5
Mg^{2+}, mg/L	0–22	3.5	8.6–26.5	15.2

3.2. Comparison of Inherent Water Quality Characteristics among Reservoir Catchments

After testing the correlation between physicochemical parameters in MAV and LF and after data processing (transformed to logarithmic scale), we found that there were significant correlations among hydrological characteristics in MAV; the strength of correlation varied from moderate (i.e., 0.5–0.6) to excellent (i.e., 0.7–0.9). To explain the effect of hydrological characteristics on water quality, we conducted a multiple regression analysis that revealed a linear relationship between dependent and independent variables for both MAV and LF, at a 5% significance level. As for the results for ML, we omitted the regression analysis because of limited monitoring data. In order to identify intercorrelation among parameters, a longer monitoring period should be employed.

The results shown in Table 5 portray the uniqueness and inherent hydrological characteristics of both reservoirs (i.e., MAV and LF). For MAV, SO_4^{2-} and COD have a significant impact on the color of water. This relationship is mostly prevalent in river systems, which can be found in various recent studies worldwide: e.g., Ajibola et al. [32] in Nigeria; Chang [33] in Republic of Korea; Kannel et al. [34] in Nepal; and Ma et al. [35] in China. Generally, the production of color from SO_4^{2-} suggests the presence of transition metal ions in the water [36,37]. The parameter COD also measures the load of organic matter [38,39], which influences the decomposition results in the liberation and intensification of the color intensity of water, as discussed previously. These trends are likely to be reflected in our results, i.e., significant relationships between SO_4^2 or COD and water color in both reservoirs. Furthermore, our results in both reservoirs showed that chloride has a significant impact on TDS (especially highly significant in MAV), which suggests that most of the dissolved solids are coming from chloride salts [40]. The results also indicate that the total hardness of water in these reservoirs (especially in MAV rather than in LF) is influenced by the amount of Ca and Mg at the significance level of 5%, and this relationship is commonly used as a baseline condition in numerous studies (e.g., Penttinen et al. [41] and Charles et al. [42]). Also, we found that TDS has a statistically significant difference between the two catchments in the aggregated model, which means that TDS is not just determined by the amount of chloride but also by other regional factors.

Estimation results imply that the quality of water, in terms of color, COD, and total hardness, is influenced by multiple physicochemical parameters in both MAV and LF. The results for color and total hardness are consistent in sign and value over study reservoirs. However, conductivity is affected by the amount of dissolved ionic salts present in the water. Since salinity is defined as the total concentration of all of the dissolved salts such as sodium chloride, magnesium, calcium sulfates, and bicarbonates [19], the salinity of LF could be coming from various types of dissolved ionic salts generated from non-point source contaminants. The regression model depicting linear relationships between the parameters investigated in LF and MAV can be used as tools for predicting the water quality of any chosen study area. For instance, by treating the concentration of chloride salts, we may expect how much the quality of water will be improved in a study catchment. The validity of the model derived in the present study needs to be tested and improved further for application.

Table 5. Regression estimates and statistical significance for three water quality indicators by study reservoir (Mare aux Vacoas (MAV), La Ferme (LF), and both reservoirs), including characteristics of hydrological variables. [1]

	MAV			LF			Aggregated Model		
	Color	**TDS**	**Total Hardness**	**Color**	**TDS**	**Total Hardness**	**Color**	**TDS**	**Total Hardness**
SO_4^{2-}	1.42 (4.01)			0.49 (2.67)			0.63 (4.23)		
COD	0.52 (3.52)			1.15 (4.22)			0.79 (5.74)		
CL^-		0.80 (6.52)			0.19 (2.07)			0.50 (5.95)	
Ca			1.01 (7.16)			0.95 (4.01)			
Mg			0.68 (4.97)			0.30 (1.19)			1.16 (10.64)
Dummy LF							−0.36 (−1.03)	1.875 (8.62)	0.20 (0.75)
constant	−0.02 (−0.11)	1.28 (5.50)	0.95 (6.41)	−0.41 (−0.96)	4.45 (16.57)	1.04 (3.34)	−0.003 (−0.01)	1.77 (9.52)	1.43 (9.83)
adj. R^2	0.41	0.42	0.70	0.42	0.07	0.75	0.40	0.64	0.70
# of observation	58	58	58	42	42	42	100	100	100

[1] The *t*-statistics for each estimated coefficient are in parentheses. If the t-statistics value is greater than 1.96, it means that there was statistical significance at the 0.05 level (within 5% of standard error).

3.3. Comparison of Surface Runoff among Reservoir Catchments Using the Curve Number Method

In this section, we investigated whether the LF catchment with 30% vegetation cover undergoes more surface runoff than the ML catchment with 78% vegetation cover. According to FAO [1], surface runoff increases in the catchment, including urban areas, which usually have lesser coverage of forest buffer and are usually engaged in various types of land-use changes. Thus, the amount of surface runoff that is generated tends to be least in the catchment with a higher coverage of forest buffer, as the extrinsic networks of trees contributes to slowing down rainwater runoff, enhancing infiltration, and also uptaking water for various metabolic processes.

The *CN* method is simple, but provides a quick response of immediate surface runoff. The *CN* of each land use is calculated from their respective coverage areas (see Appendix A for details). The estimates of weighted *CN* values for each reservoir catchment are shown in Table 6. As expected, the results demonstrate a lower *CN* value (i.e., 34.22) for ML, a low value (i.e., 39.50) for MAV, and a high value (i.e., 78.17) for LF, in inverse proportion to the coverage of their forest buffers; that is, a high *CN* value portrays poor or scarce forest coverage and/or higher scales of bad land-use practices.

The annual runoff depth and volume flowing into each reservoir are compiled in Table 6. The annual runoff depths for MAV, ML, and LF are 8.23 mm/year, 0.11 mm/year, and 83.18 mm/year, which correspond to annual volumes of 160,532.93 m^3/year, 733.47 m^3/year, and 1,631,240.40 m^3/year, respectively. These results show that the coverage of forest buffer affects the surface runoff of each catchment. The LF catchment, which is comprised of poor forest buffer coverage along with other land-use practices, exhibited higher runoff compared with the MAV and ML catchments. Then, the MAV catchment, which is comprised of 58% forest buffers, generated an intermediate volume of runoff. This finding is in agreement with the result of Scott and Lesch [43], which described that, in experimental catchments in South Africa, the plantings with eucalypts or pine trees produced significant decreases in streamflow within several (3–4) years.

Table 6. Annual runoff flowing into each reservoir.

Name	CN_{wt}	S (mm)	Forest Buffer (%)	Runoff Depth, Q_a (mm/year)	Annual Runoff from Catchment Area (m^3/year)
MAV	39.50	389.00	58	8.23	160,532.93
ML	34.22	488.19	78	0.11	733.47
LF	78.17	70.94	30	83.18	1,631,240.40

The results from Table 7 confirm that the surface runoff generated is more in the negative control catchment (i.e., LF) compared with the positive control catchment (i.e., ML). These results are consistent with the previous study of Ross [44] that reported that greater forest cover alters the *CN* to produce less surface runoff, as more water is retained in the soil. Thus, it can be postulated that a catchment with a high proportion of forest buffer coverage helps minimize the amount of surface runoffs during heavy rainfall. However, the *CN* method has many limitations that overlook many hydrological properties within catchments, such as underground/stream water supply and evapotranspiration. Hence, it does not accurately depict the amount of surface runoff and base-flow discharge that can be ignored, but it is still useful because the method provides a simple and convenient way to compare the relative magnitude of surface runoffs caused by rainfall events in three reservoir catchments.

Table 7. Surface runoff ratios.

Ratio	Units	MAV	ML	LF
Runoff volume (m^3/year)/Annual precipitation (mm/year)	m^2	49,374.845	249.875	1,200,167.86
Runoff volume (m^3/year)/Reservoir area (km^2)	m/year	0.029	0.0007	0.715
Runoff volume (m^3/year)/Catchment area (km^2)	m/year	0.008	0.0001	0.083

3.4. Comparison of Water Quantity among Reservoir Catchments Using the Water Balance Equation

Table 8 shows that MAV and ML, which are well-preserved catchments, had a higher water influx value per unit area (i.e., 1.44 m and 1.35 m, respectively), compared with LF, which was a forest-degraded catchment (i.e., 0.91 m). Also, a similar pattern was observed for the water yield. The catchments with higher forest coverage generally provide less water quantity—that is, both influx and yield—because of high water loss from evapotranspiration by trees [45,46]. However, the results in this study indicate that evapotranspiration is not a major factor to deplete water from catchments. Marion et al. [47] describe that the rate of forest evapotranspiration in response to climate change is species-dependent. Forests in the MAV catchment are mostly composed of exotic species, *Pinus eliotii*, and *Eucalyptus robusta*, while forests in the ML catchment are mostly native forests threatened by invasion with exotic species. Moreover, Kruijt et al. [48] and Marion et al. [47] argued that it has been experimentally proven that higher concentrations of atmospheric CO_2 causes a reduction in stomatal pores, leading to lower transpiration rates. Thus, the combination of tree species and elevated CO_2 may decrease the rate of evapotranspiration.

The results imply that healthy forests could also be involved in increasing the water influx and yield of catchments, possibly by maintaining good precipitation and enhancing groundwater recharge. This is supported by Aragão [49], who argued that deforestation can reduce tropical rainfall significantly, while Locatelli et al. [50] agreed with the suggestion of Aragão [49] and maintained that tropical reforestation has the potential to counteract climate change associated impacts on water supplies by re-stabilizing the hydrological cycles. Therefore, maintaining forest buffers in tropical regions are essential to protect the rainfall patterns required for the sustainable conservation of water quantity.

Table 8. Water quantity of Mare aux Vacoas (MAV), Mare Longue (ML), and La Ferme (LF) reservoirs.

Water Balance Components	MAV	ML	LF
Annual storage in 2013 (Mm^3)	19.55	4.75	6.41
Annual storage in 2014 (Mm^3)	19.32	4.57	7.34
Annual storage change in 2013–2014 (Mm^3), ΔS	−0.23	−0.18	0.93
Annual yield (=outflux) (Mm^3), $Q_{out} + GW_{out}$	33.00	9.70	17.00
Evapotranspiration in 2014 (Mm^3), ET	5.46	0.92	0.93
Annual precipitation into reservoir (Mm^3), AP	18.21	3.08	3.10
Ground water influx (Mm^3), GW_{in}	5.86	7.36	14.13
Surface runoff (=discharge) (Mm^3), Q_{in}	14.16	0.00	1.63
Mean annual water influx (Mm^3), $Q_{in} + GW_{in}$	20.02	7.36	15.76
Catchment area (km^2)	19.50	6.53	19.61
Annual water influx per unit catchment area (m)	1.44	1.35	0.91
Annual yield per unit catchment area (m)	2.38	1.77	0.98

4. Conclusions

This study investigated the effects of forest buffers on water quality and quantity in MAV in Mauritius. The study areas encompassed three reservoir catchments. We assessed the water quality by analyzing the trends of physicochemical parameters and rainfall, and determined annual surface runoff using the *CN* method. In addition, we determined water quantity through the water balance equation with respect to the percentage of forest buffer coverage. The results suggested that forest buffers have a significant impact on the water quality of MAV. The catchments with sparse and poor forest buffers were more prone to water quality degradation. Surface runoff was found to differ according to the percentage of forest buffer coverage. The catchments with less forest and more land-use types generated more surface runoff.

In general, the quantity of water tends to increase in catchments with more land-use types, because high water loss is caused by evaporation from trees. However, the results indicated that forest buffers had significant impacts on the water quantity in the study catchments, as estimated from the water balance equation. These results imply that healthy forests can increase the water influx and yield of catchments by maintaining precipitation and enhancing groundwater recharge. Thus, we found that forest buffers are important in hydrological cycles, and can enhance water production.

The analysis and interpretation of the study would have been more useful if longer monitoring data (at least 20 years) had been available. This would have allowed for the visualization of long-term trends and changes in water quality over time. Moreover, in order to obtain an accurate representation of water quality, the parallel analysis of physicochemical and biological (resident aquatic biota indicators) parameters, pesticides, and fertilizers are required. So as to sustainably conserve the water quality of MAV, it is highly recommended to either re-locate agricultural areas away from surface water courses or adopt agroforestry practices.

Furthermore, it is important that hydrologists in Mauritius consider using the Forest Service Water Erosion Prediction Project (FSWEPP) model as a tool to sustainably manage catchments. This tool can quantify the effects of forest buffers on runoff, erosion, and sedimentation. The extensive climate change challenges places Mauritius at the forefront and with urgent need to conserve its limited water resources and forest buffers.

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Appendix A

Table A1. Mare aux Vacoas (MAV) total weighted curve number (*CN*).

Land Use Type and ArcGIS Delineated Area	Cover Description: Cover Type and Hydrologic Condition	Land Use or Crop, Treatment Practice and Hydrologic Soil Groups	*CN*	Individual Weighted *CN*
Forest 11.48 km^2	Other agricultural lands: woods or forest land Good	N/A N/A A	30	24.83
Agricultural area 2.37 km^2	N/A Good	Row crops Straight row C	85	14.52
Streets and roads 0.02 km^2	N/A N/A	N/A N/A A–D	98	0.15
Reservoir area 5.60 km^2		N/A		
Total weighted *CN* for MAV: 39.50				

Table A2. Mare Longue (ML) total weighted curve number (*CN*).

Land Use Type and ArcGIS Delineated Area	Cover Description: Cover Type and Hydrologic Condition	Land Use or Crop, Treatment Practice and Hydrologic Soil Group	*CN*	Individual Weighted *CN*
Forest 5.05 km^2	Other agricultural lands: woods or forest land Good	N/A N/A A	30	27.70
Agricultural area 0.42 km^2	N/A Good	Row Crops Straight Row C	85	6.53
Reservoir area 1.05 km^2		N/A		
Total weighted *CN* of ML: 34.22				

Table A3. La Ferme (LF) total weighted curve number (*CN*).

Land Use Type and ArcGIS Delineated Area	Cover Description: Cover Type and Hydrologic Condition	Land Use or Crop, Treatment Practice and Hydrologic Soil Group	*CN*	Individual Weighted *CN*
Good quality forest 3.17 km^2	Other agricultural lands: woods or forest land Good	N/A N/AA	30	5.50
Bad quality forest 2.70 km^2	Arid and semi-arid range lands: herbaceous mixture of grass, weeds and low growing brush Poor	N/A N/A C	87	13.58
Agricultural area 7.71 km^2	N/A Poor	Row Crops Straight Row C	88	39.16
Photovoltaic panels 0.27 km^2	Impervious area N/A	N/A N/A A–D	98	1.52
Settlement 3.46 km^2	Residential districts with 65% mean impervious area N/A	N/A N/A D	92	18.41
Reservoir area 2.28 km^2		N/A		
Total weighted *CN* of LF: 78.17				

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