The Effect of Landuse Changes on River Resources of the Kaimai Hydropower Catchment, New Zealand

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ABSTRACT

Since the introduction of intensive farming, New Zealand has undergone substantial land use changes involving large areas. These changes influenced New Zealand's development as an agricultural economy, but they have also affected runoff. The exact magnitude of runoff changes is seldom known, although we can often hypothesize on the type of change. Land use changes are continuing and these changes may alter runoff. This would be important for rivers where the supply of water is committed for hydroelectric power development. Statistical analysis and rainfall-runoff models are generally used to explain, describe and predict water movement through a catchment. Both methods were used to study the impacts of landuse changes on river resources of the Kaimai Hydropower Catchment. Long term rainfall records and power generation data (MW) were used for the analysis. GIS was used to map the areas of landuse change. Data analysis showed that if the present structure of the Kaimai Hydropower and rainfall regime did not change, there would be little or no impact of landuse changes on river resources of the hydro catchment.

1 INTRODUCTION

Forestry has contributed substantially to the economic growth of the country over the last 60 years, and is likely to play an important role in the future, based on the projected afforestation of over 50,000 ha per year. In addition, the introduction of plantation forests on land previously in pasture has served to protect many unstable areas from erosion (Fahey, 1994). The Ministry of Forestry (1994) has reported 1.3 million ha of exotic forest in New Zealand.

In the 1950s, there was a growing awareness that water as a multi-purpose resource was also a finite commodity. Although it was clear that the large-scale conversion of one vegetation type to another could influence streamflow, little was known about the magnitude of these changes in New Zealand. Accurate and reliable scientific information on the relationship between landuse and water yield were needed for sound management decisions, on the allocation of scarce water resources and for evaluating the likely impacts of proposed development (Fahey and Rowe, 1992).

The Kaimai Hydropower catchment in New Zealand has undergone changes in landuse since 1982 in several parts of the catchment. This paper discusses the impacts of landuse changes on the operation of the Kaimai Hydropower scheme. It is important for the management of any hydro scheme to assess available water resources and any possible impact of landuse changes on operation.

2 STUDY AREA

The study area covers approximately 350 km^2, 14km southwest of Tauranga City. The Kaimai Hydropower project consists of three Hydropower stations, Lloyd Mandeno (LMS), Lower Mangapapa (LMPP) and Ruahihi, commissioned in 1976, 1979 and 1981 respectively. The total system production is 41.6 MW. Based on the geology and topography the study area can be divided into the northern Mamaku Plateau (which comprises the bulk of the area), the lower eastern Kaimais and the southern Whakamarama Plateau. Native forest, with smaller areas of exotic forest and scrub, covers the catchment almost entirely. A variety of native trees grow in the gorges and valleys of the study area, particularly in the more inaccessible areas. Figure 1 shows the digital elevation model (DEM) of the study area along with the description of Kaimai Hydropower scheme.

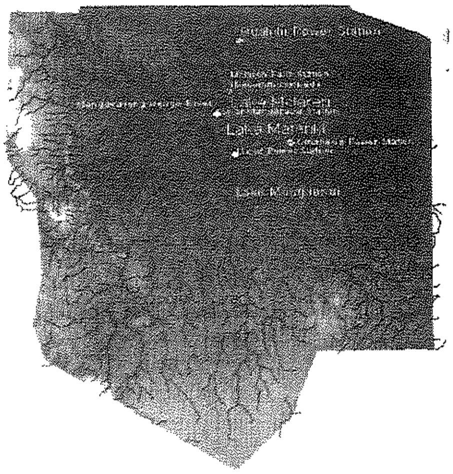

Fig. 1Kaimai Hydropower scheme and digital elevation model of the catchment area.

3 DATA USED AND LIMITATIONS

Major approaches used to examine the impacts of land use changes on stream flow may include statistical data summary, water balance modelling, black-box rainfall-runoff modeling, comparative study of adjacent catchments, and overlaying before and after landuse change maps using geographical information systems (GIS). Unfortunately, all the above-mentioned approaches require good quality rainfall and runoff data which are not available for the Kaimai Hydropower catchment. Monthly statistical reports of power generation are the only available data which show the total power being generated for that period. Knowing the hours run by the machines during the month, the MW data were converted into machine outflows for all the three hydro power stations LMS, LMPP and Ruahihi. Landuse changes were estimated by using the OVERLAY and EDITTOOLS capabilities of the ARC/INFO-GIS. It was found that 6323 ha out of 10635 ha of planned forest in the Kaimai Mamaku region was planted.

4 STATISTICAL DATA ANALYSIS

Seasons	Rain (mm) 1968-81	Rain (mm) 1982-95	T-Test Statistics
Spring	178 ± 19.1	176 ± 33.5	1.52
Summer	145 ± 28	152 ± 32	1.365
Autumn	198 ± 39	162 ± 34	0.111
Winter	215 ± 18.4	194 ± 28.5	-.359
Annual	2268 ± 257	2065 ± 284	1.148

Table 1 Seasonal and Annual Rainfall Comparison (Critical T-Test value=2.055 at 5% sign. Level)

Table 1 shows the seasonal and annual rainfall comparison for the period of 1968-81 (before land use change) and 1982-95 (after land use change).

The mean data before and after landuse changes were checked by using t-test to see whether the difference in the means of two samples is a true difference or the increase/decrease is within the random data variation. Results showed that the calculated t-statistics for all the seasonal and annual rainfall were less than the critical t-value. This means that there is no significant difference in the means of the data before and after landuse change. However, machine outflow data were not available for the period of 1968-81 so, it is not possible to compare the rainfall records with the outflow records.

LMS and LMPP power stations had machine outflows available from 1981-to date and 1984-to date for the Ruahihi power station. Machine outflows and rainfall data were divided into two periods 1982-88 and 1989-95 for LMS and LMPP stations, 1984-89 and 1990-95 for Ruahihi station in order to see the changes in the rainfall and their corresponding impact on machine outflows (Table 2a, 2b).

Station/ Rain	Seasons	1982-88	1989-95	T-Stat.
LMS	Autumn	5.54 ± 0.20	5.34 ± 0.8	0.64
	Winter	6.26 ± 0.39	6.87 ± 0.6	-2.13
	Spring	5.87 ± 0.3	6.42 ± 0.53	-1.73
	Summer	5.54 ± 0.62	5.2 ± 0.56	0.917
	Annual	5.91 ± 0.2	6.01 ± 0.53	-0.428
LMPP	Autumn	6.03 ± 0.39	5.79 ± 0.99	0.586
	Winter	6.87 ± 0.5	7.67 ± 0.64	-2.53
	Spring	6.32 ± 0.25	7.18 ± 0.73	-2.12
	Summer	4.90 ± 0.99	5.26 ± 1.3	-.554
	Annual	6.31 ± 0.17	6.75 ± 0.7	-1.457
Rain (mm)	Autumn	156 ± 62.3	170 ± 50	-0.527
	Winter	177 ± 46.65	217 ± 36	-1.918
	Spring	170 ± 61.81	187 ± 47.2	-0.655
	Summer	174 ± 65.67	130 ±23.75	1.54
	Annual	2043 ± 544	2139 ± 380	-0.548

Table 2a Seasonal and annual rainfall and machine outflows comparison for LMS and LMPP stations. (Critical T-Test value=2.178 at 5% sign. level)

It was assumed while making this comparison, that the period 1982-88 was a time when the area had been clearfelled initially and the trees were young, and 1989-95 was a time when the trees had started growing and were making hydrological impacts (if any). Similar assumptions were made for the Ruahihi power station.

T-test results showed that the difference in the means for the comparison period was within the random data variation (table 2a). No landuse change was detected from this comparison.

Station/ Rain	Seasons	1984-89	1990-95	T-Stat.
Ruahihi	Autumn	9.79 ± 1.6	10.66 ± 1.6	-0.99
	Winter	12.96 ± 1.4	14.71 ± 1.6	-2.13
	Spring	11.46 ± 2.6	12.5 ± 1.0	-0.96
	Summer	11.17 ± 2.1	9.62 ± 1.6	1.51
	Annual	11.59 ± 1.1	12.05 ± 1.3	-0.68
Rain (mm)	Autumn	148 ± 58.4	168 ± 6.1	-0.59
	Winter	176 ± 46	174 ± 45	-0.86
	Spring	176 ± 66.7	180 ± 43	0.07
	Summer	170 ± 74.1	136 ± 23	1.12
	Annual	2077 ± 355	2075 ± 451	0.09

Table 2b Seasonal and annual rainfall and machine outflows comparison for the Ruahihi power station (Critical T-Test value=2.228 at 5% sign. level)

The LMS and LMPP stations cannot utilize the total runoff from the upper catchment during the major rainfall events because of the limited capacities of the feeding tunnels to the hydro lakes. In high rainfall times, the spillage from the upper catchment goes directly to Lake Mclaren by passing Lloyd Mandeno and Lower Mangapapa stations. Lake Mclaren receives most of the flow from the upper catchment and the Mangakarengorengo river catchment.
As Lake Mclaren receives most of the runoff from the catchment, it was decided to recheck the t-test results using only the Ruahihi seasonal and annual data. Regression analysis was carried out for the comparison period between rainfall and outflows. Three statistical models (separate slope and intercept, common slope and separate intercept, common slope and common intercept) were used to check the slight change in slopes for the autumn and spring seasons. All three models were used as full and reduced models and data were encoded for that purpose. The F-test table was used to find whether the slope was significant or not. No significant difference in slopes was detected for the autumn and spring seasons and no landuse change impact was again detected for the comparison period.

5 WATER BALANCE

The study of water balance applies the principal of conservation of mass. For any arbitrary volume and during any period of time, the difference between total input and output will be balanced by the change of water storage within the volume. The water balance for any water body and any time interval can be written by:

Inflow - Outflow = Change in Storage

Inflow represents the precipitation received at the ground surface (runoff) and subsurface inflow (base flow), and change in storage represents the amount of water being lost or could not become the part of the outflow. Complete water balance requires the data of all its components such as evaporation, transpiration, interception and ground water loss. As no data are available on the above mentioned components, a simplified water balance equation will be used for this study to determine the effects of land use changes on outflows. The equation will be of the form:

Rainfall - Runoff = Water Loss

5.1 Water Loss

LMS station had the longest available annual records of outflows and rainfall therefore it was decided to use LMS data for water balance calculations. Data were grouped into seven years periods (1975-81, 1982-88 and 1989-94) representing before, during and after land use change. Seven years of water balance showed there was approximately 50% (1m/year) of water loss. Estimation of outflow to rainfall ratios also showed an approximate loss of 1m/year (table 3 a,b). Similar results were obtained for LMPP and Ruahihi stations.
By using the evapotranspiration (ET) value of 1.0 m/year for the study area [Wells (1974), Pearce (1979), Dons (1981) and Dell (1982)], there is no or very little loss to ground water. It can be concluded that the Kaimai Hydropower is having approximately 50% water loss for the comparison periods. At present, afforestation seem to have no impact on outflows.

6 POWER OUTPUT AND RAINFALL

The average total system export for the year 1984-89 was compared with the 1990-95 data (as all the stations were functional in 1984). The average total systems export for the years 1984-89 was 159.28 GWH and for the year 1990-95 was 162.42 GWH. There seems to be no significant difference in the systems export. Comparison of rainfall data with the systems export yearly basis shows a clear relationship between rainfall and the systems export (Fig. 2). It is reasonable to conclude that the outflows are more related to rainfall. Regression analysis of Ruahihi export and rainfall (Fig.3), total systems export and rainfall also suggests that landuse change has had no significant impact.

7 CONCLUSION

The hydrological literature generally concludes that water yield increases after harvesting, and decreases after planting. This is usually the case when all, or a high percentage of the catchment has undergone a land use change. In the case of the Kaimai Hydropower catchment, a very small area of the catchment has undergone that kind of landuse change at one time. Data analysis shows no impact of land use change on the river resources of Kaimai Hydropower. The only observed impacts of land use change on the river resources were observed in terms of rubbish and sediments in the hydro lakes after clearfelling between 1983-84 (Pers. comm. With staff). According to the present management plan of the Tasman forestry (owners of the catchment forest), it is unlikely that the Hydropower will again witness similar problems.

If the present structure of the Kaimai Hydropower (and the catchment) remain the same, and the rainfall regime does not change, there will probably be little or no impact of land use change on river resources. Finally, it can be concluded from this study that no impact of land use changes on the operation of the Kaimai Hydropower scheme has been detected.

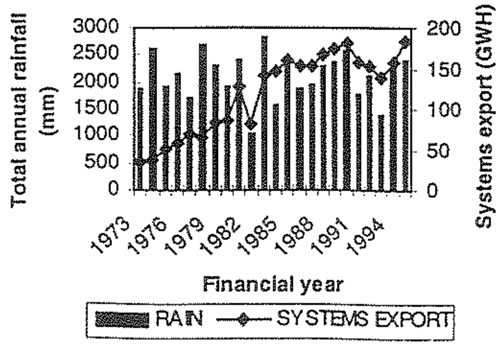

Fig. 2 Total systems export and rainfall

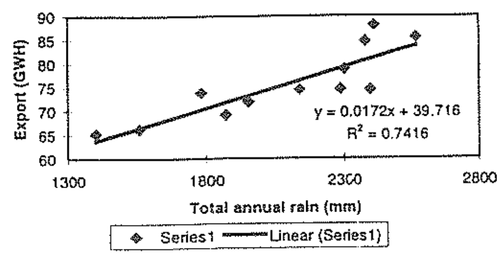

Fig. 3 Corelation between annual rainfall and Ruahihi station export

	MEAN (%)		
STATION	1975-81	1982-88	1989-94
LMS	A	B	C
OUTFLOW /RAIN	46.04	50.3	49.12

Table 3b Comparison of outflow to rainfall ratios for LMS station

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	COMPARISON OF RAINFALL AND RUNOFF REDUCTION								
STATION			ANNUAL MEAN		REDUCTION		AN. MEAN WATER LOSS		
A	B	C	D	E	F=C-D	G=C-E	H=C3-C2	I=D3-D2	J=E3-E2
		1975-81	1982-88	1989-94	1982-88	1989-94	1975-81	1982-88	1989-94
LMS m^3/s	1	5.72	5.91	5.91	-0.1900	-0.0190	1.1700	1.0100	1.0700
m	2	0.99	1.03	1.03	-0.0400	-0.0400			
RAIN (m)	3	2.16	2.04	2.10	0.1200	-0.0600			

Table 3a Comparison of water loss for LMS station