An Assessment of the Physical Impacts of Agricultural Development on the Valley River Watershed

by

Patrick Terence McGarry

A Practicum Submitted
In Partial Fulfillment of the
Requirements for the Degree,
Master of Natural Resources Management

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MASTERS OF NATURAL RESOURCE MANAGEMENT

ABSTRACT

The Valley River is a traditional walleye (Stizostedion vitreum) spawning stream that contributes to the Lake Dauphin walleye population. Large reductions in the commercial catch of walleye led to the investigation of the impact of agricultural development on spawning habitat in the Valley River. The investigation described in this report centered on the physical changes in the watershed associated with agricultural land development. The study assessed changes in land use, the hydrologic regime, soil loss and sediment delivery.

Air photo and LANDSAT satellite imagery showed that cultivated acreage more than doubled between 1948- 1980 in the watershed. Woodlands decreased by 44% and wetlands by 90% in the same period. Spring runoff hydrograph analysis showed 1965 - 81 hydrographs to have higher peak flow rates, faster time to peak and steeper recession limbs than 1913-28 hydrographs. The changes in the hydrograph shape are believed to be the result of changes in land use between 1913-81. Hydrologic modelling using SCS and HYMO models demonstrated the effects of land use change on two sub-watersheds of Valley River. The models predicted that land use caused an 8% increase in peak flow on Silver Creek and 12% increase on Pleasant Valley Creek between 1948-80. Soil loss and sediment analysis using the USLE showed that land use changes contributed to increases in soil loss and sediment delivery between 1948 - 1980.

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CHAPTER I INTRODUCTION

1.1 PREAMBLE

A study was initiated by the Manitoba Department of Natural Resources, Fisheries Branch, titled "Valley River Environmental Study". The objectives of the study were to identify and assess natural and anthropogenic changes to the physical, chemical and biological parameters of the Valley River. The anthropogenic changes include agricultural, recreational and industrial development. The physical impact of agricultural development on the Valley River is the subject of this study.

Several Provincial agencies cooperated with the Fisheries Branch in assessing the impact of agriculture on the Valley River Watershed. They included; The Manitoba Department of Agriculture; the Environmental Management Branch; the Water Resources Branch; and the Manitoba Centre for Remote Sensing. The Department of Agriculture conducted a survey in the study area from which information was available on soils and field topography. The Environmental Management Branch conducted a water quality survey on the Valley River during 1982 and 1983.

1.2 BACKGROUND

1.2.1 The Lake Dauphin Fishery

Up to 1930 Lake Dauphin was one of the most productive commercial fishing waters in Manitoba for walleye (*Stizo-*

stedion vitreum). It produced 1290 kg/km^2 of walleye in 1929 which was more than twice the production of Lake Manitoba and 3.5 times that of Lake Winnipeg (Cunningham 1936). Part of the reason for the tremendous production was the "ideal" spawning habitat found in the six streams draining into Lake Dauphin (Cunningham 1936). Historically the Lake was known as a natural wonder for walleye production.

The commercial fish harvest declined significantly between 1931 - 1978 . Records for the period reveal a two to three fold decrease in commercial fish harvests by weight (Figure 1.1). During the same time period, the dollar value of the catch declined by almost four fold due to a shift in species composition (MDNR 1976). Walleye showed the greatest reduction in the catch.

The number of fisherman and per capita catch have also shown a decline (MDNR open files, Figure 1.2). Tests on Lake Dauphin suggested that food supply to the fish population was not a limiting factor (Mcleod and Moir 1945, Valiant pers. comm.). The walleye population also proved to be healthy, based on the strength and distribution of year classes (Valiant pers. comm.). It was concluded that the reduction in walleye was most likely due to loss of spawning habitat in streams draining into the Lake.

An investigation on Crooked Creek, which drains into

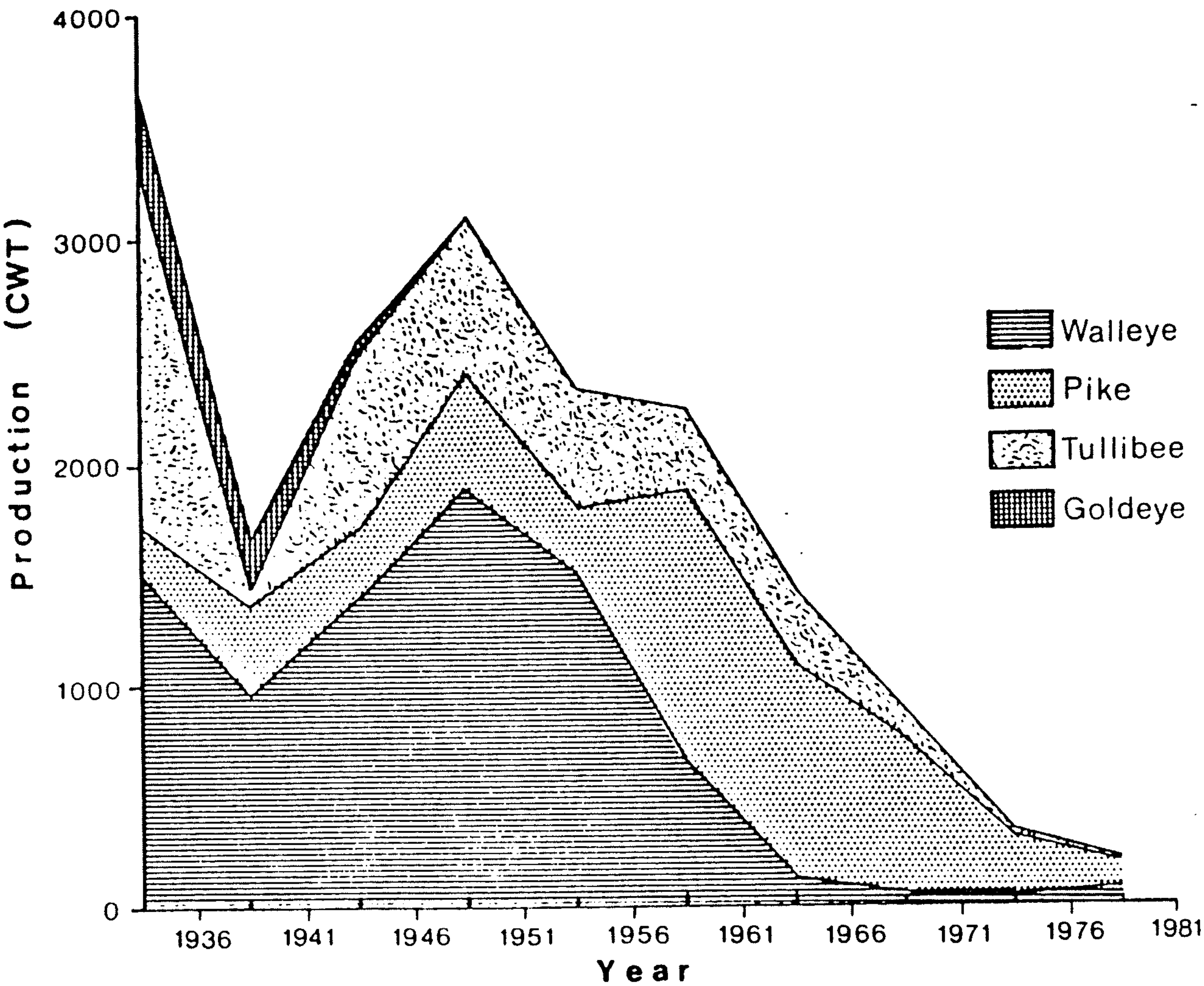
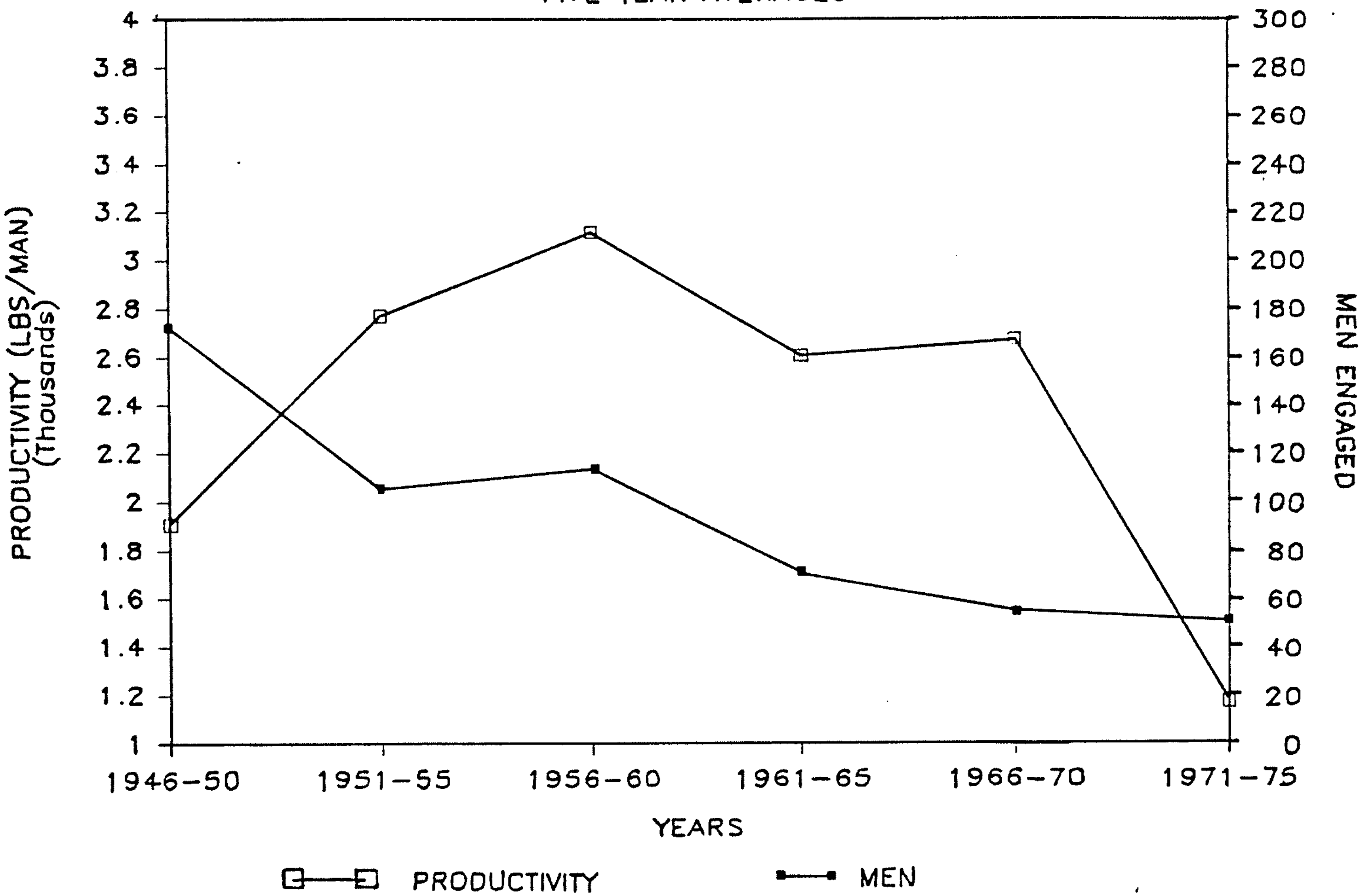


Fig. 1.1 Dauphin Lake commercial production shown as five-year averages from 1931 to 1981. (From Gaboury 1985)

Figure 1.2

LAKE DAUPHIN FISH PRODUCTION

FIVE YEAR AVERAGES



the southwest corner of Lake Dauphin, showed that due to increases in sediment load walleye were prevented from spawning in the creek (MDNR 1976). The increased sediment loading was the result of land drainage and clearing.

1.2.2 Land Use

The development of land for agricultural purposes has many potential impacts on a watershed in terms of water quality, flow regimes, and sediment load (Zittlau 1979, Seecharan 1980, Jenkins 1974). The cause of change in these factors can be divided into land clearing, land drainage, and land management (Zittlau 1979). Clearing the land can increase the velocity of overland flow and magnitude of peak flows and hence soil erosion, which in turn can cause an increase in sediment load. This can be detrimental to a fishery for a number of reasons. Increases in siltation on spawning beds, bed and channel erosion, and occurrences of flooding are all factors that adversely effect spawning habitat in streams.

Land drainage is often used to recover previously unusable land for cultivation or to ensure crop flood protection. Drainage can cause changes in periodicity of flow, magnitude of high and low flows, and loss of headwater storage (Found et al. in Zittlau 1979). These factors are important to the success of fish reproduction. In streams such as the Valley River the duration of peak flow in spring coincides with the spawning run of certain cool-water species. Therefore, increases in the speed of runoff could cause water levels to recede before spawning is complete.

A recent study listed the potential environmental impacts associated with land degradation due to agricultural land use (Coote et al. 1981, Table 1.1). The severity of these impacts depends on the land management or cultural practices employed in working the land, such as the use of summerfallow, tillage, burning, fertilizers, and crop rotation. Appropriate cultural techniques can greatly reduce environmental impacts from agriculture.

An integral part of the watershed is the water resource itself. Water is a dynamic resource moving within the water cycle. Water falls as precipitation,and either moves along the ground as surface water or infiltrates below ground level to move as ground water which eventually returns to the atmosphere by means of evaporation and transpiration, to again form precipitation. The manner of water movement through the system depends upon the surface and subsurface characteristics of the watershed (Toye et al. 1972). Water movement is also influenced by climate, topography and man. In assessing anthropogenic changes to a watershed the features of the entire water cycle must be considered.

By assessing land management practices, the extent of clearing and drainage, and the nature of the water resource, a comprehensive picture of changes in the watershed and related fishery can be composed. From this information land use and land management recommendations can be made.

Table 1.1 Some Environmental Effects of Agriculture (from Coote et al. 1981)

1) Water Pollution - surface water:

Eutrophication	- Nitrogen,Phosphorus from erosion and runoff
Contamination	- pesticides and heavy metals from erosion and runoff

2) Water Pollution - groundwater:

Contamination	- Nitrate and salts from contaminated soils may move by deep percolation, together with some pesticides and heavy metals if present in the soil in sufficient quantities

3) Sedimentation - from soil erosion

Wildlife	- destruction of fish spawning grounds filling of ponds, sloughs, etc., which are habitats for many species of wildlife

4) Air Pollution - from wind erosion

5) Wildlife Contamination - from plants and insects contaminated by uptake of pesticides, heavy metals, etc., present in soils

6) Desertification - from wind erosion, soil contamination

7) Flooding - excess runoff, drainage deterioration, sedimentation and landslides.

1.3 PROBLEM STATEMENT

Agricultural practices and development involves loss of vegetative cover, and soil erosion from uncontrolled runoff, occurs as a result. Soil loss can greatly reduce agricultural productivity and also have an effect on water quality. Sedimentation and siltation on spawning areas can occur when soil particles enter natural drainage channels from cultivated fields. In addition, changes in timing and duration of peak flow events from runoff may result from agricultural development, which can negatively impact the spawning run of spring fish migrations in the river.

Soil loss and runoff are serious management problems in a watershed since they area responsible for erosion, gullying, sedimentation, flooding and water pollution (Zittlau 1979, Coote et al. 1981). Problems of this nature endanger the agricultural base and the biotic community downstream. Degradation of agricultural land and a fishery are problems that may have a common solution in comprehensive watershed management.

1.4 OBJECTIVES

The main objective of the study was to assess the physical impacts of agricultural development on the Valley River Watershed. In particular, the study aimed to assess the impact of land use change on soil loss, sediment yield, and the hydrologic regime.

1.4.1 Sub-objectives

The sub-objectives of the study were to:

1) document the changes in land use, in the Valley River Watershed, and the riparian zone of the Valley River between 1948 and 1980.

2) determine the impact historical land use changes have had on spring runoff and peak flow rate in the Valley River.

3) determine the effects of historical land use change on surface runoff models in two unguaged sub-watersheds of Valley River (Pleasant Valley and Silver Creeks).

4) determine the impact of historical land use change on soil loss and sediment yield in two sub-watersheds (Pleasant Valley and Silver Creeks).

5) identify areas within the sub-watersheds with excessive soil loss or sediment delivery.

1.5 DESCRIPTION OF STUDY AREA

The Valley River watershed is bordered to the north and south by the Manitoba Escarpment, and to the east by Lake Dauphin. Lake Dauphin is situated east of the foothills of the southern portion of Duck Mountain and the northern portion of Riding Mountain (Figure 1.3). The general slope of the land is to the north and east from the mountains. The slope ranges from steep to gradual through the foothills to Lake Dauphin. Duck and Riding Mountains are part of the Manitoba Escarpment which is believed to be the ancient shore of Lake Agassiz.

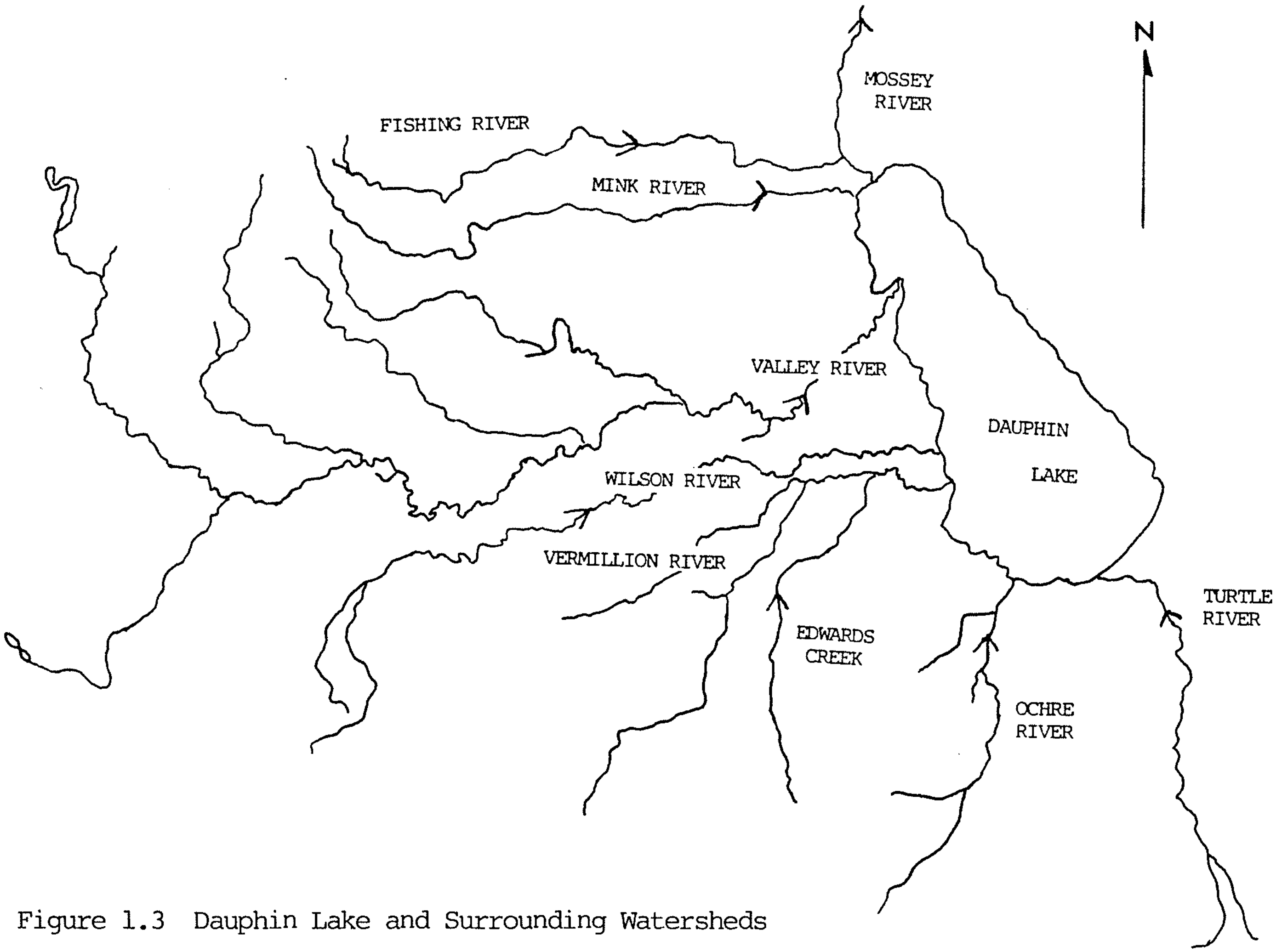


Figure 1.3 Dauphin Lake and Surrounding Watersheds

All the sizeable inflowing streams to Lake Dauphin originate in the rugged hills of glacial drift and flow down through a sloping plain of clay and loam interspersed with gravel ridges (Mcloed and Moir 1945). Of the many rivers draining Duck Mountain, only the Valley River flows into Lake Dauphin.

Lake Dauphin is approximately 536 km^2 in area and has a maximum depth of 4.5 to 5 meters. The shore is low, and the surrounding terrain is flat. The bottom is sandy for 50 - 90 meters from shore. Beyond this, it is composed of clay and silt up to 7.7 meters thick. The original post-glacial bottom is composed of gravel and boulders (Stewart-Hay 1951).

The Valley River drains an area of slightly over 2850 km^2. Its headwaters lie in the upper reaches of the Duck Mountains at an elevation of 700 meters. The elevation at the mouth of the river where it enters Lake Dauphin is 260 meters. Total relief for the watershed is approximately 440 meters. Most of the land (90%) below the 548.8 m (1800 ft.) contour line, which is roughly 50% of the watershed has been cleared. About 40 - 45% of the land is forested and most of it lies in Duck Mountain Provincial Forest and Park.

Agricultural development began in the 1880's with the most readily accessible land being occupied by 1900. Soils are typically CLI agriculture class 2x and class 3 - 4 with some soil and topographic restrictions (CLI 1968).

Soils in Class 2 have moderate limitations on the range of crops and class 3 - 4 soils have moderately severe to severe limitations on the range of crops and productivity. Soils in the Duck Mountains have not been classified for agricultural capability. The principal crops are wheat followed by oats, barley, tame hay, mixed grain, rapeseed and rye (CLI 1968).

1.6 METHODS

The methods used in this study to achieve the objectives are summarized as follows:

1. A present and historical land use map was developed with the aid of air photos and LANDSAT imagery. Land use data were generated for the years 1948, 1969 and 1980. Land use interpretation was based on the Canada Land Inventory Classification system. The Manitoba Remote Sensing Centre provided the interpretation and digital image analysis.

2. Numerical and statistical analysis were performed on the hydrometric record to determine if there had been a change in the spring runoff hydrograph. The spring hydrographs were analysed in detail and multiple regression models developed to elucidate a change related to land use over time.

3. The SCS (Soil Conservation Service) model and the HYMO (Hydrologic Model) model were used to assess the effect land use had on a design storm runoff hydrograph. Land use for 1948, 1969 and 1981 was used for input into the models and the response evaluated. The models were used on two sub-watersheds of Valley River, Silver and Pleasant Valley Creeks.

4. The universal soil loss equation (USLE) was used to estimate soil loss in parts of the watershed. Determination of several factors in the USLE was required. The equation was applied

on a sub-watershed scale and not at the individual field level.

5. A sediment yield equation developed by Williams (1975) was used to evaluate the effect land use had on sediment yield. The storm hydrographs developed from No.3 above, were used as input to the equation. Three years were simulated based on the land use data from 1948, 1969, and 1980. The equation was applied to Silver and Pleasant Valley Creeks.

1.7 BOUNDS OF THE STUDY

The study is not intended to assess socio-economic factors relating to the watershed. Neither is it intended to quantify the cause - effect relationship between agricultural development and changes in fish populations.

The study intends only to identify physical changes in the watershed associated with agriculture and evaluate the watershed's response.

CHAPTER II METHODS

2.1 LAND USE ANALYSIS

Air-photo coverage of the study area was available for the years 1948 and 1969. The photos were obtained at scales of 1:15,840 for 1948 and 1:50,000 for 1969. Interpretation was performed by remote sensing personnel according to the Canada Land Inventory System of classification. The classification system has been adapted to Manitoba conditions (Hodgson 1973). Table 2.1 shows the eight land use types used in the project. The technical methods of land use determination are further detailed in Pokrant and Gaboury (1983).

Area measurements of the land use types were done on an electronic planimeter by remote sensing personnel. The data were compiled by individual section for 1948 and 1969. Interpretation and area measurement for 1980 land use were done on a digital analyser. The 1980 land use data were compiled by sub-watershed within the study area. Comparison of land use changes between different years was accomplished by compressing the 1948 and 1969 data into sub-watershed units.

Several computer programs were written to analyse and collate the three years of data. The data analysis was designed to compare the change in land use on a study area, sub-watershed and watershed basis. The detailed output of the programs is presented in Appendix 1.

Table 2.1 **Land Classification**

Classification Code	Description
A: Agriculture	All land in cereal and forage crops
W: Woodland	Includes deciduous and conifer classes (productive and non-productive).
S: Summerfallow	Tilled fields bearing no crops.
P: Pasture	Improved grazing and/or hay cutting areas (native grasses).
K: Rough Graze	Rough, unproductive areas which may be used for grazing. May contain up to 25% scrub brush.
WL: Wetlands	Low lying areas and fringes of lakes supporting aquatic vegetation.
L: Lakes	All open water bodies.
U: Urban	Town sites.

2.2 HYDROGRAPH ANALYSIS

Several different methods were used to extract the impact of land drainage and clearing on the annual flood hydrograph. All methods used flow data from the hydrometric record. Flow data were available on Valley River from as far back as 1912, but it was incomplete. Table 2.2 summarizes the available flow data. The data were actually obtained from two stations, but there was no correction made for the slightly different sized drainage areas. The data were available on magnetic tape for computer analysis.

Table 2.2 Flow Data Summary.

Station	Years Available	Gross Drainage Area
05LJ010	1948 - present	2870 km^2
05LJ004	1913 - 1928	2720 km^2

The analysis concentrated on the peak flow and the recession limb of the spring runoff hydrograph. The time to peak (Tp) and the ascending limb of the hydrograph were not analysed due to poor data recording prior to 1948.

2.2.1 Normalized Data

Several comparisons of the flow data were made using the technique of normalizing the data. The technique was used in a study on the Red River by U.S. Geological Survey (Miller 1982). Normalized flood hydrographs were used to measure changes in flood response in North Dakota and Minnesota (Miller 1982).

The spring runoff event was separated from each year's data by taking 15 days before spring peak flow and 45 days after. The total number of days data taken for each year was 61 when the peak flow day was added. Each day of the period was then divided by the peak flow to get a relative value for the flow on a given day as compared to the peak flow. The data were normalized in this way for each year of record. The hydrographs were then divided into 3 time periods and averaged. For example, the normalized hydrographs were averaged for the period 1913-1928 and then plotted as one hydrograph to compare to the next period 1948-1964 (Figure 3.15).

2.2.2 Odd - Even Analysis

To test the possibility that any observed differences in the data were due to anomalies in the data, odd-even analysis was performed on the years available. The data were divided into odd and even years for each time period and then plotted. If plotted results showed little difference, then any previously observed differences between periods were probably not due to data selection.

2.2.3 Averaging and Other Analysis

The spring hydrographs were averaged for each time period by using the peak flow date as the focus point. The daily discharge values were averaged for 15 days prior to peak flow and 45 days post peak flow. The averaged hydrographs were then plotted for each time period.

Another technique was used for evaluating the change in the magnitude and duration of spring peak flows. Daily discharges were divided by the total discharge occurring in a 60 day period following peak flow. The results were averaged for the three periods and plotted.

Further analysis included adjusting the hydrographs to the average annual flood. The spring flood hydrograph for selected years from each time period were divided by the average annual flood flow of 120 m^3/sec [1]. The results were grouped and plotted as an average for each period.

The recession limb of a flood hydrograph usually represents water coming from storage after excess rainfall has ceased. Although some water may still come from overland flow. There is a typical decay function associated with the recession limb that can be mathematically described by the equation;

$$Q_2 = Q_1 e^{-t/k} \qquad \text{Gray (1970)}$$

Where: Q_1= instantaneous discharge rate at t_1
Q_2= instantaneous discharge rate at t_2
k = recession constant
t = elapsed time interval $(t_2 - t_1)$

The recession curve and consequently K is a function of the physical features of the watershed and channel. The K coefficient was determined for the spring flood hydrograph for each year of data. A K value was calculated at up to 3 positions on the hydrograph; 1-4 days, 5-9 days, and > 10 days after the peak flow.

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[1] From Water Resource Branch, Man. Dept. of Natural Resources, Winnipeg.

Hydrographs were plotted on semi-log paper in order to linearize the recession limb of the hydrograph. K is constant along a straight line and can be determined from the plots. K was determined for spring snowmelt events only.

2.3 HYDROLOGIC MODELLING

2.3.1 SCS Model

The SCS model estimates surface and subsurface runoff and peak discharge rate (SCS 1972). The inputs to the model are drainage area of a hydrologic unit, longest flow length, average basin slope, design precipitation, and average curve number (CN) for the soil type and land use.

The SCS model was applied to 2 sub-watersheds of Valley River. The Silver Creek and Pleasant Valley watersheds were divided into hydrologic units (HU) for several reasons. First, it allowed the isolation of areas with high runoff or peak flow. Second, the HYMO model that was used for flood routing in conjunction with the SCS model was calibrated on watersheds of less than 65 km^2. HUs were defined based on channel slope, drainage area, and areas of topographic continuity. The stream profile was plotted and major breaks in the slope were identified. Boundaries were then drawn on a map based on the above criteria.

The longest flow length for each HU was determined using a digitizer. The average basin slope was determined using a grid point intersection method (SCS 1972b).

Rain storms have characteristic time patterns that are specific to a geographic area. The SCS (1972a) has defined these into storm types with a distinctive intensity and distribution of rainfall over time. The maximum 6 and 24 hour rainfall intensity for a 10 year return period storm is used to define the storm type for design rainfall.

The models both use design rainfall events to estimate the flood hydrograph. Design precipitation was based on a 24 hour rainfall with a return period of 10 years (1972b). Rainfall frequency curves were obtained from AES[1] for Dauphin Airport. The 24 hour precipitation (P_{24}) = 93.1 mm for a 10 year return period. The temporal distribution of a 24 hr storm for Dauphin airport was found to be Type II, based on the P_6 / P_{24} ratio (SCS 1972b). The Type II mass rainfall curve for Valley River is shown in Figure 2.1.

Soil type and land use were incorporated into the SCS runoff model by the use of a soil cover/complex number (CN). The SCS (1972a) provides tables for the definition of CN values for different land uses and soil types. The CN value is a relative measure of the proportion of surface runoff resulting from hydrologic soil properties and land use when all other factors are equal.

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[1] Atmosphere Environment Service, Environment Canada, Winnipeg.

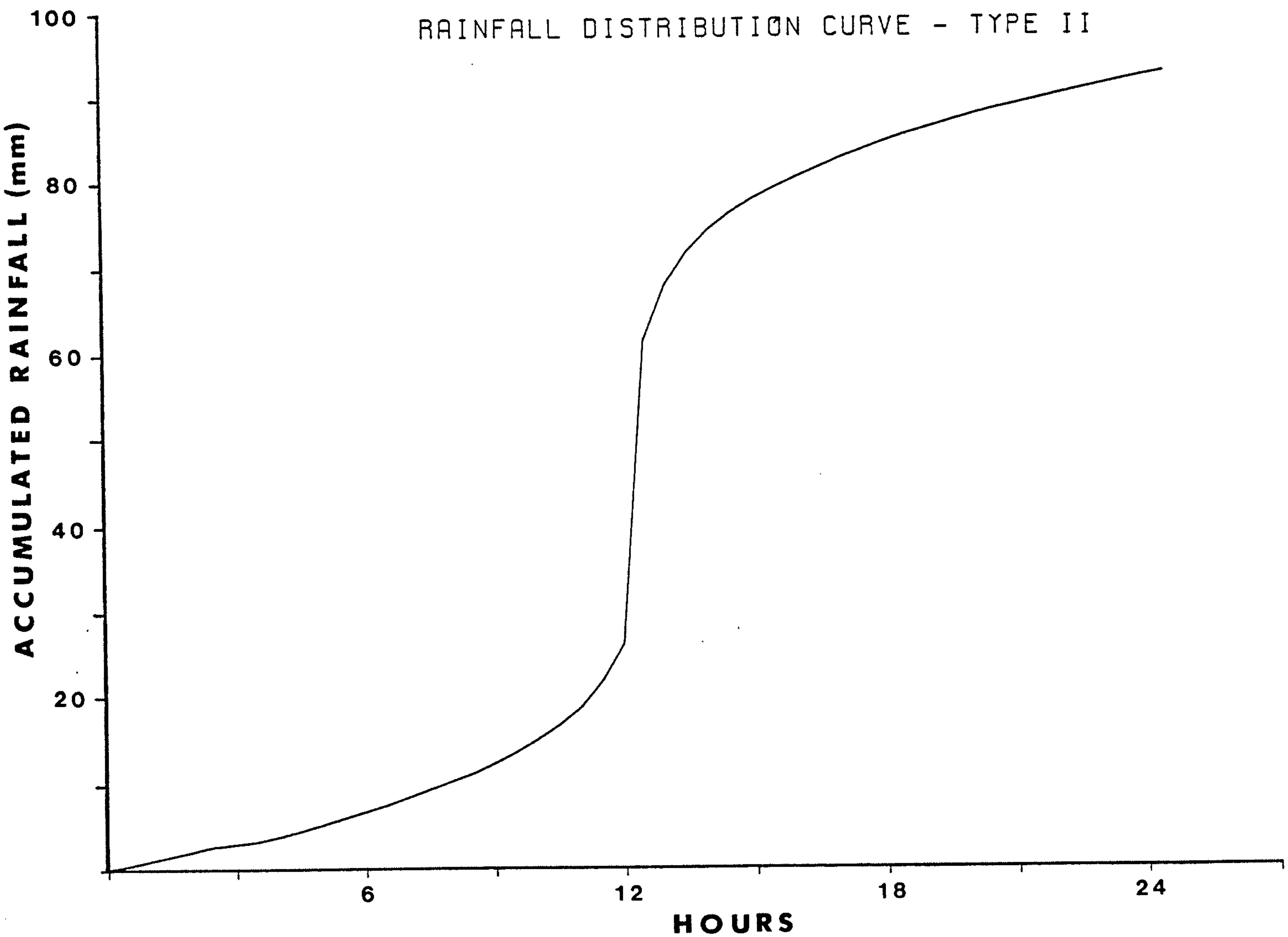

Figure 2.1 SCS Rainfall Distribution Curve - Type II.

The soils in Pleasant Valley and Silver Creek watersheds were classified according to the SCS procedure. Soil group A has low runoff potential and high infiltration and transmission rates, while soil group D has high runoff potential and slow infiltration rates.[1]

The soil groups were then overlaid on the land use maps of each year studied 1948, 1969 and 1981. For each land use category (eg: agriculture), a CN value was assigned based on the hydrologic soil group it was in. Every land use category had a CN value assigned to it and then the weighted CN for the HU was calculated. The CN values actually used for the land uses in the study area were modified slightly to account for different soil types such as peat. Table 2.3 shows the list of CN values used for each land use and soil type.

To determine storm runoff the SCS procedure uses the following formula:

$$R = \frac{(P - Ia)^2}{(P - Ia) + S} \qquad (1)$$

Where: R = estimated runoff
Ia= initial abstraction of moisture by soil
S = potential maximum moisture of soil
P = storm precipitation

SCS engineers found that the Ia prior to the occurrence of

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[1] The hydrologic soil groups were assigned to Valley River Soils by L. Slevinsky, Man. Dept. of Agriculture.

runoff was equal to 0.2 times the maximum water retention of the soil (S).

$$Ia = 0.2\ S \qquad (2)$$

Substituting into Equation 1:

$$R = \frac{(P - 0.2\ S)^2}{(P + 0.8\ S)} \qquad (3)$$

S in Equation 2 is determined by soil type and land use or cover. The relationship between S and CN is:

$$S = \frac{1000}{CN} - 10 \qquad (4)$$

Table 2.3: CN Values for Land Use/cover

Land Use	**Hydrologic Soil Group** A	B	C	D	Pt*	Er
Small Grain (slope < 2%)	61	73	81	84	-	-
Summerfallow	77	86	91	94	-	-
Pasture	38	61	75	81	39	80
Rough Graze	41	63	75	81	39	80
Woods	27	55	70	77	25	77
Yard	51	68	79	84	-	-

Wetland	(on line)	78
Wetland	(off line)	20
Lake	(on line)	100
Lake	(off line)	20

* Pt= Peat; organic soils
  Er= Eroded Slopes Complex

Tables of CN values for various combinations of hydrologic soil group and land use are available for 3 categories of antecedent moisture condition (AMC). The AMC is determined by the amount of precipitation falling on a watershed in the 5 days preceding the storm of interest. The AMC falls into one of three groups based on the following:

AMC I = 0 - 3.55 mm
AMC II = 3.55 - 5.33 mm
AMC III = > 5.33 mm

CN values for AMC II were used in the current study. The final relationship for determining runoff is found by substituting Equation 4 into Equation 3:

$$R = \frac{(P + 2 - 200/CN)^2}{(P - 8 + 800/CN)} \qquad (5)$$

The design peak discharge is computed by:

$$Q = \frac{(484. \times DA \times RO)}{((0.133 \times Tc/2) + 0.6 \times Tc)} \qquad (6)$$

Where: DA = drainage area (mi^2)
RO = runoff (inches)
Tc = time of concentration (hr)
Q = peak discharge (cfs)

Runoff is determined from equation 5 and the drainage area from topographic maps. Tc is computed by the following equation:

$$Tc = \frac{L^{0.8} * (S + 1)^{0.7}}{1140. * Y^{0.5}} \qquad (7)$$

Where: Tc = time of concentration (hr)
L = longest flow length (ft)
S = maximum soil moisture retention
Y = basin slope (%)

Design flood hydrographs were computed from the runoff volume and peak discharge of the unit hydrograph (1972a). Two computer programs were written to determine the SCS flood hydrograph. The flood hydrograph was determined by incrementally applying rainfall excess on the unit hydrograph (SCS 1972a). As noted previously, type II rainfall distribution was used in the calculations.

The SCS model uses lumped parameters in the runoff calculations which does not account for the spatial variability in the watershed. Factors that influence runoff are averaged for the whole basin. This approach omits the fact that certain land uses and locations are more influential on runoff than others. Some of the sensitivity of the model is lost by weighting or averaging the CN values. However, such a situation is unavoidable unless the area is broken into an excessive number of sub-areas. The design rainfall used in the model does not account for the spatial and temporal distribution of normal rainfall events. Therefore, simulated storms may represent unrealistic precipitation events. Given the limitations of the model it still provides reasonable estimates of the impact of land use on the hydrologic regime.

2.3.2 <u>HYMO</u>

HYMO (HYdrologic MOdel) is a computer model designed by the USDA Agricultural Research Service (Williams and Hann

1973). HYMO was designed to transform rainfall data into runoff hydrographs and route them downstream through reservoirs and streams. The program uses the same equation as SCS to determine runoff volume but has different computations for determining the unit and design flood hydrographs.

Since there were eight HUs in Pleasant Valley and nine in Silver Creek, flood routing was necessary to obtain a design flood hydrograph for the whole of each watershed. The model required at least 1 stream cross section for each HU and Manning's roughness coefficient (n) for segments of the cross section. Cross section information was obtained from the Water Resources Branch, Manitoba Department of Natural Resources. Where cross section information was unavailable, it was estimated from nearby cross sections. Manning's n values were estimated for the flood plain and channel based on descriptions found in Gray (1970).

There were many potholes or small wetlands distributed throughout most of the sub-watersheds. In Silver Creek watershed the potholes were given a CN value of 20, which indicates low runoff potential, and included in the calculations. The wetland was given some potential for runoff in the design rainstorm because of the relatively steep topography. In Pleasant Valley watershed, the wetlands not on the time of concentration route (Tc) and without a hydraulic connection to the creek, were considered non-contributing in terms of runoff and were deleted from the drainage area.

2.4 MULTIPLE REGRESSION ANALYSIS OF HYDROLOGIC PROCESSES

Two dependent and 4 independent variables were used in the regression analysis (Table 2.4). The dependent variables were peak flow rate and runoff volume for the spring snowmelt runoff event. The independent variables were total precipitation, antecedent moisture index, melt rate index, and total improved land.

Table 2.4: Multiple Regression Variables

Dependent	Independent
PK = Peak flow rate	TP = Total precipitation
RO = Runoff volume	API = Antecedent precip. index
	MI = Melt rate index
	TIL = Total improved land

The total precipitation variable (TP) was determined for each year by studying precipitation records available from AES. The TP variable was defined as the total volume of precipitation falling on the watershed from Nov. 1 of the preceding year to the date of peak flow in spring (for peak flow equations) or to the date of the last storm contributing runoff to the spring flood hydrograph. The precipitation cut off date was determined by plotting spring precipitation on the hydrograph of the year of interest.

The precipitation data from several surrounding stations were weighted to obtain a basin average for Valley River watershed (Table 2.5). Every station did not have complete records. Whenever there were two or more stations with data for the year of interest a weighted average was calculated for the basin. Weights were assigned to each station depending on its proximity to the watershed. Daily precipitation records were not available before 1921. Earlier data were monthly only and could not be used.

Table 2.5: Precipitation Stations

Station	Station No.	Years
Ashville	5040121	1973 -
Boggy Ck.	5012470	
Dauphin A.	5040680	1942 -
Gilbert Pls	5040985	1934 -
Grandview	5041120	1935 - 1970
	5041116	1977 -
Roblin	5012471	1974 -
Russel	5012520	1912 -

Antecedent precipitation index (API) is a measure of soil moisture content prior to freeze up in the preceding calendar year. API was determined by obtaining monthly basin precipitation information from May 1 to October 31 of the preceding year. The monthly precipitation totals were then multiplied by a weighting factor and summed (Table 2.6). The resulting API was then averaged for the years of record. API for individual years was based on percent of normal or average API.

Table 2.6: API Weighting factors. (From Water Resources Branch)

MONTH	May	June	July	Aug.	Sept.	Oct.
WEIGHT	0.07	0.08	0.12	0.18	0.25	0.30

Melt rate index (MI) was calculated for the years of interest. Melt rate in spring can have a large effect on the spring flood hydrograph. The MI was calculated by computing the degree days for each day of the snow melt period. The snow melt period began when cumulative degree days above freezing exceeded five. The degree days were plotted cumulatively against time. The slope of the degree day line was the MI for the year.

Total improved land (TIL) was also used as an independent variable. It was determined by adding together the agriculture, summerfallow, and pasture land categories for the 3 years of data available from Section 2.1. The TIL variable was then plotted against year and linear interpolation was performed between points to obtain TIL for all years of the hydrometric record. A second TIL variable was computed from census figures for Dauphin, Gilbert plains , and Grandview RM's. The census figures available for TIL date back only as far as 1941.

Peak flow rate was a dependent variable and was obtained from the hydrometric record for Valley River near Dauphin (05LJ010). Runoff volume for each year was determined by measuring the area under the hydrograph. A recession limb was visually interpreted when additional rainfall fell after the precipitation cutoff date with the additional rainfall being removed from the hydrograph.

All the data were assembled by year and entered into a computer program supplied by Manitoba Water Resources Branch (Table 2.7). The program allowed the use of 9 independent variables with one dependent variable. The program used logarithmic transformation and Fletcher Optimization in the multiple regression. Log transformation produced better regressions than linear for hydrometeorologic data.

The multiple regression was tried with different combinations of independent variables in log and linear form (Table 2.8). To assess the change in hydrologic regime, the data were split into two time periods 1948-64 and 1965-81. The data were also split into odd and even years for both the time periods of interest and the entire record of 34 years. The odd-even split was used to determine whether

Table 2.7 : Multiple Regression Input Data

Year	TP (in)	API (%)	MI (° Days)	RO (in)	PK (cfs)
1948	8.89	105	9.3	2.93	7945.
1949	4.74	93	7.3	0.33	875.
1950	5.50	111	9.8	0.57	2270.
1951	5.04	111	5.6	0.70	1998.
1952	3.25	99	4.5	0.86	1670.
1953	4.94	84	1.9	0.77	1691.
1954	4.60	158	8.2	0.99	2341.
1955	3.37	126	7.2	1.36	2450.
1956	9.64	86	3.8	2.12	2659.
1957	8.68	99	2.2	1.99	2969.
1958	4.36	81	8.5	0.33	847.
1959	3.80	79	11.0	0.29	409.
1960	4.50	124	5.3	1.44	2849.
1961	2.99	53	2.9	0.03	64.
1962	5.69	63	14.7	0.24	1211.
1963	5.14	92	7.0	0.22	302.
1964	4.82	83	6.6	0.21	589.
1965	4.04	76	7.3	0.30	1288.
1966	6.26	137	8.3	0.33	2359.
1967	9.08	87	3.1	1.54	5049.
1968	4.48	90	3.0	0.32	572.
1969	4.62	69	6.5	0.64	3029.
1970	5.57	111	3.5	1.75	3884.
1971	4.01	136	13.0	1.13	4590.
1972	4.64	126	1.6	1.18	2118.
1973	2.95	61	2.8	0.06	87.
1974	7.46	165	8.3	2.41	9252.
1975	5.97	95	4.2	1.19	2751.
1976	5.21	178	8.8	1.27	3220.
1977	3.28	56	2.5	0.11	174.
1978	4.14	154	1.5	0.64	992.
1979	9.77	131	3.5	2.55	13596.
1980	5.31	84	5.0	0.60	1387.
1981	4.91	126	3.3	0.14	254.

random effects of data selection influenced the regression equations.

Table 2.8: Multiple Regression Equation Forms.

a) Linear

$$Y = A + B_1X_1 + B_2X_2 + B_3X_3 \;....\; B_nX_n$$

b) Logarithmic

$$\text{Log } Y = A + B_1\text{*Log } X_1 + B_2\text{*Log } X_2 + B_n\text{*Log } X_n$$

Where: Y = dependent variable
X = independent variable

2.5 SOIL LOSS AND SEDIMENTATION

The universal soil loss equation was used to determine soil loss and a modified version was used to estimate sediment yields (Wischmeier and Smith 1978, Williams 1975). These equations were developed in the United States and therefore many assumptions were made concerning their use in Manitoba. Several authors have already used the USLE in Manitoba (Slevinsky and Shaw 1978, Steele 1979, Seecharon 1979, Eilers 1983, Langman 1983). These papers provided the necessary background information for using the equation on the Valley River Watershed.

2.5.1 USLE

Soil loss equations were developed in the U.S. to allow planners and land managers to predict the average annual rate of soil loss due to water erosion under different crops, cropping and management practices. The USDA developed the USLE from 10,000 plot years of basic runoff and soil loss data (Wischmeier and Smith 1978). The USLE is an empirical soil loss equation that is believed to be applicable wherever numerical values of its factors are known. The equation reduces the need to do site specific erosion studies. It is an invaluable tool to the watershed manager or soil conservationist.

The USLE measures soil loss due to sheet and rill erosion only, on an average annual basis. It is not intended for use on storm events (Foster 1983). Sheet erosion is the uniform removal of soil particles, organic matter and soluble nutrients. Rill erosion occurs when runoff begins to concentrate along paths of least resistance. The force of flow exceeds the resistance of the soil structure to flow, and results in the formation of shallow channels called rills. This can eventually lead to gully erosion.

The information required to use the equation falls into six categories as defined in Table 2.9. The factors have been developed for most geographic areas of the U.S. and are

Table 2.9: Universal Soil Loss Equation (USLE).

The soil loss equation is:

$$A = R\ K\ (LS)\ C\ P$$

where:

A, is the computed soil loss per unit area, expressed in the units selected for K and for the period selected for R. In practice, these are usually selected so that they compute A in tons per acre per year, but other units can be selected.

R, the rainfall and runoff factor, is the number of rainfall erosion index units, plus a factor for runoff from snowmelt or applied under water where such runoff is significant.

K, the soil erodibility factor, is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 72.6 ft. length of uniform 9 percent slope continuously in clean-tilled fallow.

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6 ft. length under identical conditions.

S, the slope-steepness factor, is the ratio of soil loss from the field slope gradient or that from a 9 percent slope under otherwise identical conditions.

C, the cover and management factor, is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.

P, the support practice factor, is the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to that with straight-row farming up and down the slope.

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available on tables from USDA. The USLE is relatively new in use in Manitoba and only a few factors have been developed for specific areas. The development of the USLE began in Manitoba in 1978 (Slevinsky and Shaw 1978). Recent soil survey reports have included USLE factors (Eilers 1983). Langman (1983) developed a soil erosion nomograph for soil series in the Westbourne area. The lack of USLE factors for the study area required initial development. Steele (1979) developed a rainfall erosion factor (r) for the Dauphin area based on 17 years data. The USLE has also been used in Southern Ontario and soil loss potential tables have been established (Wall et al. 1981). The remaining factors and their variations were calculated for the study area.

2.5.2 USLE Factors

2.5.2.1 R Factor

The R factor or rainfall erosion potential was previously calculated for years 1960-76 at Dauphin Airport (Table 2.10). This is the closest station to the Valley River watershed. A continuous rainfall recorder is required to determine the R factor because the maximum 30 minute intensity is required to determine R for each storm. The R

Table 2.10: Rainfall Factor For Dauphin Airport.

YEAR	R	Rs	Rt
1960	30.86	4.53	35.39
1961	11.79	4.17	15.96
1962	65.36	6.41	71.77
1963	60.04	5.06	65.10
1964	260.27	4.97	265.24
1965	35.36	4.10	39.46
1966	30.77	2.94	33.71
1967	16.46	6.17	22.63
1968	16.58	3.89	20.47
1969	34.20	5.11	39.31
1970	36.48	4.26	40.74
1971	11.51	3.90	15.41
1972	7.89	4.31	12.20
1973	55.77	3.45	59.22
1974	7.49	7.59	15.08
1975	39.43	6.75	46.18
1976	18.36	6.66	25.02
Average			48.41

Table 2.11: LS values from contour extreme point method.

Stream	H.U.	Slope Len. (L) ft	Slope(S) (%)	LS
Pleasant Val.	1	6650	2.26	0.721
	2	1264	2.13	0.452
	3	1643	1.93	0.452
	4	2897	3.48	0.982
	5	2934	2.35	0.632
	6	1800	2.12	0.499
	7	1467	2.78	0.596
	8	2309	1.30	0.382
Silver Ck.	1&2	2850	3.23	1.217
	3&4	1349	2.66	0.559
	5&6	1630	2.83	0.626
	7	1609	5.18	2.240
	8	1699	1.45	0.373
	9	1000	1.16	0.278

factor is the product of rainstorm kinetic energy and maximum 30 minute intensity.

$$R = E \times I_{30}$$

Where: E = rainstorm kinetic energy in 100s of foot-tons per acre
I_{30} = maximum 30 minute rainfall intensity (in/hr)

To obtain a yearly R value, EI_{30} for every storm greater than 0.45 inches was summed.

In northern temperate climates, soil loss and erosion due to snowmelt runoff and rainfall on frozen ground can be significant. The EI30 factor does not apply to frozen ground conditions. An Rs factor was created to account for snowmelt runoff (Wischmeier and Smith 1978). Rs equals the total precipitation falling between December 1 and March 31 multiplied by 1.5. Rs is then added to R to get R total (Rt). The multiplier (1.5) was determined from empirical data (Wischmeier and Smith 1978).

Eilers and Langman (1985) calculated an R factor for Dauphin Airport using an equation developed by Ateshian (1974). The formula is:

$$Rt = 0.417\ P^{2.17} + Ps$$

Where: Rt = the total erosivity factor
P = the 50% frequency (1 in 2 year) rainfall of 2 hour duration
Ps = the snow depth on the ground on the last recording date in March, converted to water equivalents.

The factor calculated from the formula can be used as a first approximation. However, the spot measure of snow depth is extremely variable and may be unreliable as a predictor of snowmelt runoff. Two test plots in southern Ontario, 50 m apart had snow depths of 600 and 250 mm prior to snowmelt (Van Vliet and Wall 1981). The snow depth was recorded at the same time and indicates the variability of snow depth measurements.

The Rt factor was calculated for the Dauphin Airport station using the Ateshian formula (Eilers 1983). The Rt factor equaled 52.12. The Rt factor used for the Valley River was 48.51. It was calculated by adding Steele's (1979) R factor and an Rs factor calculated for snowmelt runoff (Wischmeier and Smith 1978).

2.5.2.2 LS Factor

The LS factor is a combined term for length of slope and percent slope. It is defined by the equation:

$$LS = (\lambda/72.6)^m \quad (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$$

Where: LS = length/slope factor

λ = slope length (ft)
θ = slope in degrees
m = 0.5 for slopes $>$ 5%
m = 0.4 for slopes of 3.5 - 5%
m = 0.3 for slopes of 1 - 3%
m = 0.2 for slopes $<$ 1%

LS for the study area was developed for each sub-watershed based on a method developed by Williams and Berndt (1977) for use in small-medium sized watersheds (Table 2.11). The Williams equation for slope is called the contour length method. The equation is:

$$S = 0.25\ Z\ (LC25 + LC50 + LC75)\ /\ DA$$

where:
- S = % slope
- Z = total watershed height (km)
- LC25, LC50, LC75 = contour length at 25,50 and 75% of Z, respectively (km).
- DA = drainage area (km^2)

Length of slope was calculated by the following formula. It is called the Contour Extreme Point method (Williams and Berndt 1977).

$$\lambda = \frac{LC \times LB}{2 \times EP \sqrt{(LC^2 - LB^2)}}$$

Where:
- λ = length of slope (ft)
- LC = length of contour (ft)
- LB = length of base contour (ft)
- EP = number of extreme points on the contour

The same contours were used to calculate slope (S), and slope length (L), for each sub-watershed in Silver Creek and Pleasant Valley Creek.

2.5.2.3 K Factor

Soil erosion that is directly attributable to the inherent properties of the soil is called the soil erodibility or K factor. The soil erodibility factor can be calculated from the nomograph in Wischmeier and Smith (1978) or from the formula supplied. The equation is:

$$100\ K = 2.1\ M^{1.14} \times 10^{-4}\ (12-a) + 3.25(b-2) + 2.5(c-3)$$

Where: K = soil erodibility
M - (%Silt & %very fine sand)(100 - %Clay)
a = percent organic matter
b = structure code
c = permeability code

The principle factors that effect the potential for soil erosion are the percent very fine sand and percent silt in the topsoil; the percent of organic matter in the topsoil; the soil structure; and the soil permeability in the whole profile.

The finer the soil structure the less impact raindrops have on soil detachment and transport. The soils in the Valley River watershed had soil structure classes assigned based on the following code:

1 - very fine granular
2 - fine granular
3 - medium or coarse granular
4 - blocky, platy, or massive

Large amounts of organic matter in the topsoil reduce the soil's susceptibility to erosion by reducing rainfall impact on soil particles and absorbing more precipitation. Organic matter has the most effect on the K factor when it is between 0 and 4%. At higher values the organic matter effect is reduced.

The more permeable the profile the faster the surface layers can abstract water and reduce runoff. The soil permeability code was assigned to Valley River soils based on the following system:

1 - rapid
2 - moderate to rapid
3 - moderate
4 - slow to moderate
5 - slow
6 - very slow

The K factors were developed for the soils of interest from soil survey reports and with the assistance of R.G. Eilers (pers. comm.). The factors are presented in Table 2.12 for each soil series in Silver and Pleasant Valley Creeks. A description of the soil associates found in the Valley River watershed is provided in Table 2.13. The physiographic regions of the watershed are shown in Figure 2.2.

2.5.2.4 C Factor

The cropping management factor C is the ratio of soil loss under specified crops and management to the soil loss on a clean tilled fallow field. The factor is a combination of land cover and residue management during a specific crop

Table 2.12: K Factor Determination For Valley River Soils

Soil Series	Soil Texture (%)			Organic Mat. (%)	Struct. Code	Perm. Code	K Factor	Erosion* Class
	Si+vfs	Sand	Clay					
Assiniboine				4.0		5	0.20	3
Benchlands	30.5	52.4	17.1	4.0	2	2	0.10	2
Blackstone	43.7	7.8	48.5	4.78	3	5	0.18	2
Dutton	62.2	10.1	27.7	4.5	2	3.5	0.24	3
Duck Mtn.	50.7	18.7	30.6	4.54	2	4	0.20	3
Erickson	53.9	25.2	20.9	4.18	2	3	0.23	3
Erick. Mod.	53.9	25.2	20.9	4.18	2	4	0.25	3
Gilbert	21.2	63.4	15.4	4.0	2	3.5	0.10	2
Grifton	41.9	32.5	25.6	4.13	2	2	0.13	2
Marringhurst		N.A.						
Meharry	41.2	32.5	26.3	13.05	2	4	0.19	2
Meharry DP	51.6	20.5	27.9	5.81	3	4	0.23	3
Onanole	46.3	23.7	30.0	4.0	2	2	0.14	2
PLainview	50.3	9.1	40.6	4.0	3	4	0.21	3
Roseridge	46.1	23.5	30.4	6.17	2	4	0.15	2
Waitville	49.8	28.2	22.0	5.37	3	4	0.23	3
Waitville M	47.4	39.7	12.9	5.37	3	4	0.24	3

Sources: Ehrlich et al (1959) p.92-96
Steele (1979)
Eilers (1983)
Pers. Comm. R.G. Eilers
Author

Erosion* Class	Erosion Hazard	K value
1	Negligible	< 0.10
2	Very Slight	0.10-0.20
3	Slight	0.20-0.30
4	Moderate	0.30-0.40
5	Severe	0.40-0.50
6	Very Severe	< 0.50

* From: Langman 1983

Table 2.13 Description of Valley River Soils (after Ehrlich et al 1959)

Key to Associations	Soil Associates or Local Genetic Types Occurring in Association		
	Well-Drained Members	Imperfectly Drained Members	Poorly Drained Members
A. Black Associations			
1. Dominant associate is an Orthic Black:			
(a) Soils developed on till of shale, limestone and granitic rock origin: (1) Newdale association (i) Newdale undulating phase (ii) Newdale modified phase	Orthic Black Degraded Black	Gleyed Black Gleyed Degraded Black	Orthic Meadow Calcareous Meadow Saline Meadow Peaty Meadow
(b) Soils developed on medium textured lacustrine deposits: (1) Dutton association (i) Dutton clay loam (ii) Dutton clay loam, till substrate phase	Orthic Black	Gleyed Black Black Solonetz	Orthic Meadow Saline Meadow Peaty Meadow
(c) Soils developed on gravelly and coarse sandy deposits: (1) Marringhurst association	Orthic Black Thin Black	Gleyed Black	Orthic Meadow Peaty Meadow
(2) Agassiz association	Orthic Black Thin Black Degraded Black	Gleyed Black	Orthic Meadow Peaty Meadow
2. Dominant associate is a Degraded Black: (a) Soils developed on medium textured lacustrine deposits: (1) Kenville association	Degraded Black Orthic Black	Gleyed Black Gleyed Degraded Black Gleyed Grey Wooded	Orthic Meadow Peaty Meadow Grey Wooded Gley
3. Dominant associate is a Gleyed Solonetzic Black: (a) Soils developed on fine textured lacustrine deposits: (1) Dauphin association (i) Dauphin clay (ii) Dauphin clay, till substrate phase	Orthic Black Degraded Black	Gleyed Black Gleyed Solonetzic Black Black Solonetz Black Solodized-Solonetz	Orthic Meadow Saline Meadow Peaty Meadow
4. Dominant associate is a Gleyed Black: (a) Soils developed on till of strongly acid shale and granitic rock origin: (1) Keld association	Degraded Black	Gleyed Black	Orthic Meadow Peaty Meadow
(b) Soils developed on fine textured lacustrine deposits: (1) Plainview association (i) Plainview clay (ii) Plainview clay, till substrate phase	Orthic Black Degraded Black	Gleyed Black Gleyed Solonetzic Black	Orthic Meadow Saline Meadow Peaty Meadow
(c) Soils developed on medium textured lacustrine deposits: (1) Lakeland association (i) Lakeland loam (ii) Lakeland loam, till substrate phase (iii) Lakeland clay loam (iv) Lakeland clay loam, till substrate phase	Orthic Black	Gleyed Calcareous Black	Calcareous Meadow Saline Meadow Peaty Meadow
(d) Soils developed on coarse textured deposits: (1) Gilbert association (i) Gilbert sandy loam (ii) Gilbert sandy loam, till substrate phase	Orthic Black Degraded Black	Gleyed Black Gleyed Degraded Black	Orthic Meadow Peaty Meadow
B. Grey Wooded Associations.			
1. Dominant associate is a Dark Grey Wooded (a) Soils developed on till of shale, limestone and granitic rock origin: (1) Erickson association (i) Erickson clay loam (ii) Erickson modified phase	Degraded Black Dark Grey Wooded	Gleyed Black Gleyed Degraded Black Gleyed Dark Grey Wooded	Orthic Meadow Peaty Meadow Saline Meadow Grey Wooded Gley
(b) Soils developed on till of limestone and granitic rock origin: (1) Rose Ridge association	Dark Grey Wooded Degraded Black	Gleyed Rendzina Gleyed Degraded Black Gleyed Dark Grey Wooded	Peaty Meadow
(c) Soils developed on medium textured lacustrine deposits: (1) Onanole association (i) Onanole sandy loam (ii) Onanole clay loam (iii) Onanole clay loam, till substrate phase	Degraded Black Dark Grey Wooded	Gleyed Black Gleyed Degraded Black Gleyed Dark Grey Wooded	Orthic Meadow Peaty Meadow Grey Wooded Gley
(d) Soils developed on gravelly and coarse sandy deposits: (1) Leary association	Orthic Black Degraded Black Dark Grey Wooded	Gleyed Degraded Black Gleyed Dark Grey Wooded	Orthic Meadow Peaty Meadow Grey Wooded Gley

Table 2.13(continued)

Key to Associations	Soil Associates or Local Genetic Types Occurring in Association: Well-Drained Members	Imperfectly Drained Members	Poorly Drained Members
2. Dominant associate is a Gleyed Dark Grey Wooded:			
(a) Soils developed on sandy deposits:			
(1) Selina association			
(i) Selina sand			
(ii) Selina sand, till substrate phase	Dark Grey Wooded Orthic Grey Wooded	Gleyed Black Gleyed Degraded Black Gleyed Dark Grey Wooded	Orthic Meadow Saline Meadow Peaty Meadow Grey Wooded Gley
3. Dominant associate is an Orthic Grey Wooded:			
(a) Soils developed on till of shale, limestone and granitic rock origin:			
(1) Waitville association			
(i) Waitville loam			
(ii) Waitville modified phase	Dark Grey Wooded Orthic Grey Wooded	Gleyed Dark Grey Wooded Gleyed Grey Wooded	Degraded Meadow Peaty Meadow Grey Wooded Gley
(b) Soils developed on till of limestone and granitic rock origin:			
(1) Grifton association	Dark Grey Wooded Orthic Grey Wooded	Gleyed Dark Grey Wooded Gleyed Grey Wooded	Peaty Meadow Degraded Meadow
(c) Soils developed on till of dominantly limestone origin:			
(1) Garson complex	Orthic Grey Wooded Dark Grey Wooded	Gleyed Grey Wooded Gleyed Dark Grey Wooded	Peaty Meadow Calcareous Meadow
(d) Soils developed on till of shale clay, limestone and granitic rock origin:			
(1) Duck Mountain complex	Orthic Grey Wooded	Gleyed Dark Grey Wooded Gleyed Grey Wooded	Peaty Meadow
(e) Soils developed on medium textured lacustrine deposits:			
(1) Rackham association			
(i) Rackham fine sandy loam			
(ii) Rackham clay loam	Dark Grey Wooded Orthic Grey Wooded	Gleyed Dark Grey Wooded Gleyed Grey Wooded	Degraded Meadow Peaty Meadow Grey Wooded Gley
4. Dominant associate is a Gleyed Grey Wooded:			
(a) Soils developed on shale clay till:			
(1) Blackstone association	Orthic Grey Wooded	Gleyed Dark Grey Wooded Gleyed Grey Wooded	Peaty Meadow
C. Regosolic Associations.			
1. Dominant associate is a Rendzina:			
(a) Soils developed on strongly calcareous till:			
(1) Meharry association			
(i) Meharry clay loam			
(ii) Meharry clay loam, deep phase	Rendzina	Gleyed Rendzina	Calcareous Meadow Saline Meadow Peaty Meadow
(2) Isafold association	Rendzina	Gleyed Rendzina	Calcareous Meadow Peaty Meadow Saline Meadow
2. Alluvial soils:			
(a) Recent alluvium:			
(1) Edwards association			
(b) Flood plain deposits in various stages of development:			
(1) Assiniboine complex	Moderately well drained soils occur near the stream channels, but imperfectly and poorly drained soils occupy the flat areas behind the river levees.		
D. Unclassified soils.			
1. Variable textured deposits on river terraces in various stages of soil development:			
(1) Benchlands complex	Well, imperfectly and poorly drained soils.		
2. Variable textured deposits on sharp slopes in various stages of soil development:			
(1) Eroded slopes complex	Excessively drained soils.		
3. Organic soils of variable thickness:			
(1) Peat	Very poorly drained soils.		

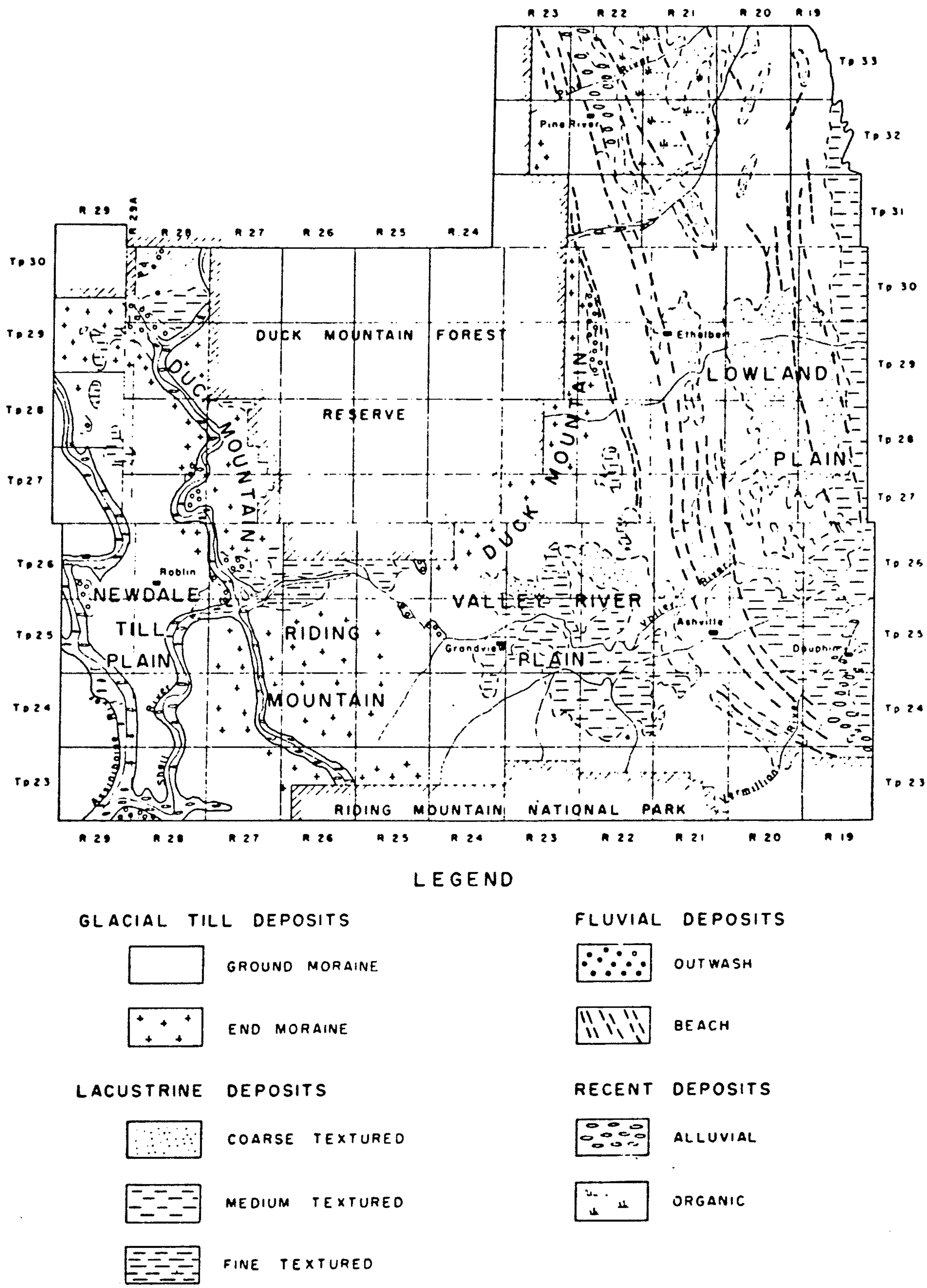

Figure 2.2 Surface Deposits and Physiographic Areas

stage. Crop sequence influences the length of time between successive crop canopies and it also effects the benefits gained from previous crop residues. The crop provides canopy protection from raindrop impact to the soil. Crop residues can be removed, left on the surface, incorporated near the surface or plowed under. The effectiveness of crop residue management will depend on the amount of residue available, which is related to the crop and crop yield on the specific site.

Wischmeier and Smith (1978) provided detailed tables for C calculation based on crop, sequence in rotation, management and crop residue. These tables were designed to assess site specific management practices in order to reduce soil loss by adjusting crop, rotation, or cultural practice. A more generalized form of the C factor was used in this study, since the main focus was on the sediment produced from soil loss on upland sites.

Steele (1979) laid the ground work for use of the USLE in the Dauphin area. Crop periods were defined and C factors were produced for a combination of management practices and crop stages (Table 2.14). It was assumed that the previous crop was small grain and the residue from the crop was equal in weight to the crop removed. Analysis of crop data allowed development of residue quantity for small grain. Small grain includes wheat, rye, barley and oats which are the main crops grown in the area (MCIC 1985).

Table 2.14: Cropping Management Factors (C). From Steele (1979).

Land Management

1) Moldboard Plow

	Crop Period			
F	1	2	3	4
C = 0.65	0.70	0.45	0.12	0.25

2) Stubble Mulch

Residue on the Surface (t/ha)	Crop Period 1	2	3	4
0.22-0.56	0.70	0.45	0.06	0.10
0.56-1.12	0.42	0.25	0.06	0.10
1.12-1.68	0.25	0.17	0.06	0.10
1.68-2.24	0.15	0.10	0.06	0.10

3) Summerfallow

Residue on the Surface (t/ha)	Seasonal Value
0.22-0.56	0.70
0.56-1.12	0.42
1.12-1.68	0.25
1.68-2.24	0.13

C factors have been developed by others for Manitoba agricultural areas (Eilers 1983, Langman 1983). The C factors computed by Eilers (1983) were used to calculate average annual soil loss on Pleasant Valley and Silver Creeks. C factors were assigned to the various land uses as follows:

C = 0.31 for small grain

C = 0.68 for summerfallow (Sf)

C = 0.01 for rough graze (RG) and pasture (P)

C = 0.019 for forest land (W)

2.5.2.5 Limitations of USLE

The USLE does not account for soil deposition during its movement. It only measures gross soil loss and may provide over estimates for sediment yield purposes. The equation was not developed to evaluate soil loss over frozen ground or during spring runoff events. The addition of an Rs factor to account for this limitation, is still only an approximation of the erosivity of spring runoff. The R factor calculated for the Valley River was based on one precipitation station and subsequently reduces the accuracy of the results. The C and LS factors were calculated on a basin average and were intended for regional analysis. Regional application of the equation is more illustrative than definitive.

2.5.3 Storm Hydrographs and Sediment Yield

The storm hydrographs synthesized in the previous chapter were used to estimate sediment yield using Williams equation (1975).

$$S = 95\ (Q\ qp)^{0.56}\ K\ LS\ C\ P$$

Where: S = sediment (tons)
Q = runoff volume (acre feet)
qp = peak flow (cfs)
KLSCP = USLE factors

The rainfall erosivity factor R was replaced by hydrologic factors, peak flow rate, and runoff volume. The coefficient and exponent used in the equation were derived from multiple regression analysis on data obtained from watersheds in Nebraska and Texas (Williams 1975). The equation is most effective in areas where stream transport capacity limits sediment yield (Foster 1983).

The design storm that was used to make the hydrographs was assumed to occur during crop stage 2. The greatest amount of erosive rainfall occurs during crop stage 2 and it is probably the most likely time for the 1 in 10 year rainfall event (Table 2.15).

Table 2.15: Percent Rainfall Erosivity by Month

Station	Month						
	April	May	June	July	Aug.	Sept.	Oct.
Dauphin A.	1	3	20	49	20	6	1

It was decided to estimate sediment yield for several types of land management practice to compare good land management to poor. Steele's (1979) C factors were used. A C factor of 0.45 was used to represent poor land management with no residue left on the field from the previous crop year. A C factor of 0.17 was used to represent a good land management with some residue remaining on the field from the previous crop year.

Composite K and LS factors were determined for the whole of Pleasant Valley and Silver Creek so that sediment yield could be determined from hydrographs produced for the watersheds. The K factor was weighted by the area each soil group occupied in the sub watershed. Peat or organic soils in the watersheds were given a K value of 0 in the calculations. Most peat areas surrounded water bodies which then were also deleted from the weighting calculations.

2.5.4 Linear Regression Analysis of Sediment Yields

Regression analysis was performed on sediment yields obtained for the Valley River for the years 1960 - 1976. Sediment yields were obtained from Penner and Oshway (1983). The analysis was done to examine the relationship between the yearly R factor, percent Sf, and sediment yield. It was hypothesized that an increase in the percentage of summerfallow might lead to an increase in sediment yield for the same precipitation event.

CHAPTER III RESULTS AND DISCUSSION

3.1 LAND USE ANALYSIS

The Valley River watershed covers an area of 2836 km^2 (1095 $miles^2$) (Figure 3.1). There is 37.8% of the watershed within the Duck Mountain Provincial Forest and Park. There is also an additional 3497 hectares or 1.2% of the watershed in Riding Mountain National Park (Figure 3.2). Land use analysis was not done on these areas since they remain in a natural state. Air-photo interpretation and satellite imagery were used to classify the rest of the watershed into land use and cover types. The study area comprised 1786 km^2 and was classified into eight land use or cover categories. The Canada Land Inventory Classification system was used for this work.

An historical perspective of land use change was generated by interpretation of air-photos taken in 1948 and 1969. Present land use was compiled from digital analysis of LANDSAT satellite images (Appendix II).[1]

The objective of the land use classification was to document the changes that have occurred in the watershed between the years 1948 and 1980. The information generated

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[1]The air-photo analysis and digital analysis was done by the Manitoba Remote Sensing Centre, Winnipeg.

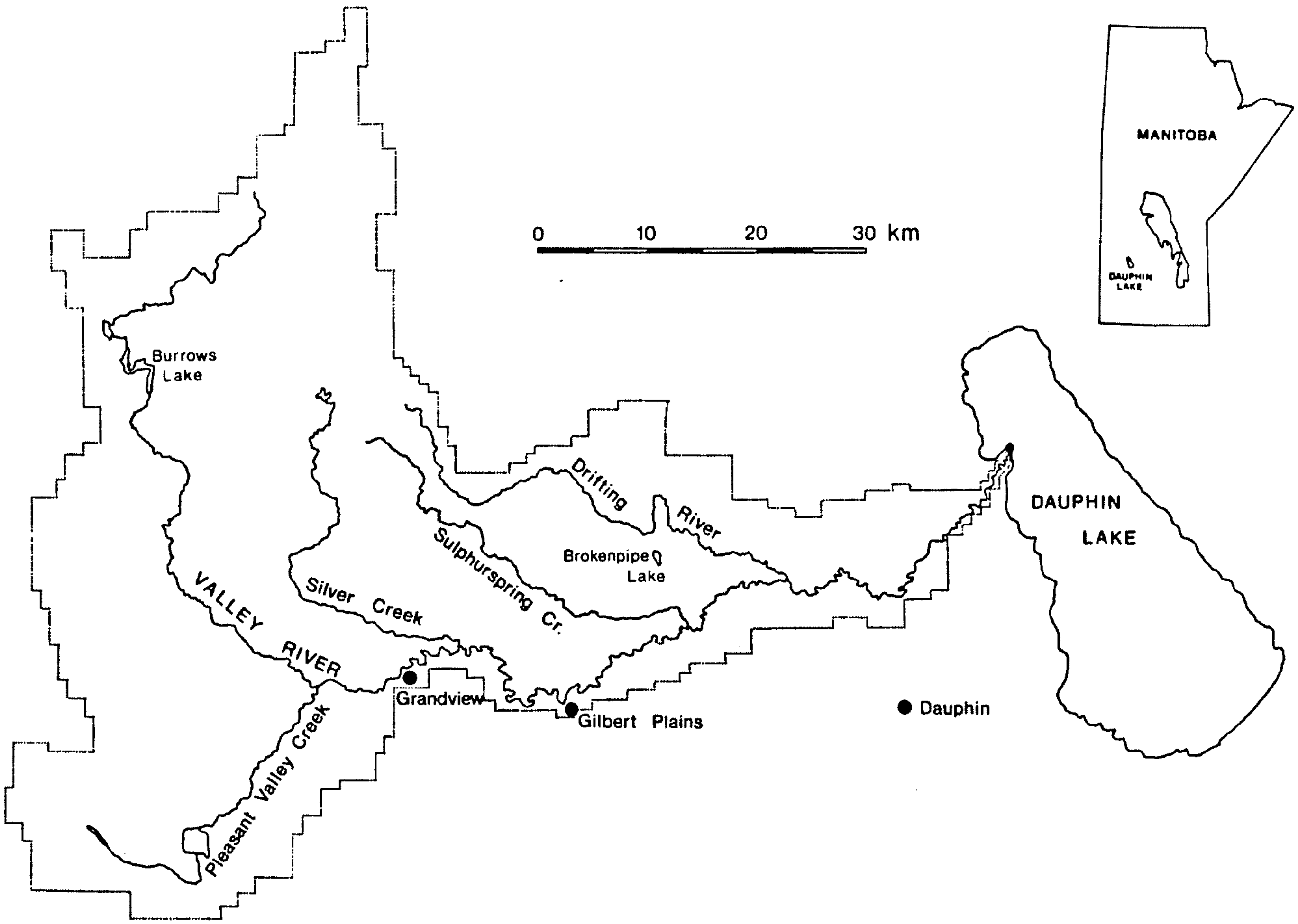
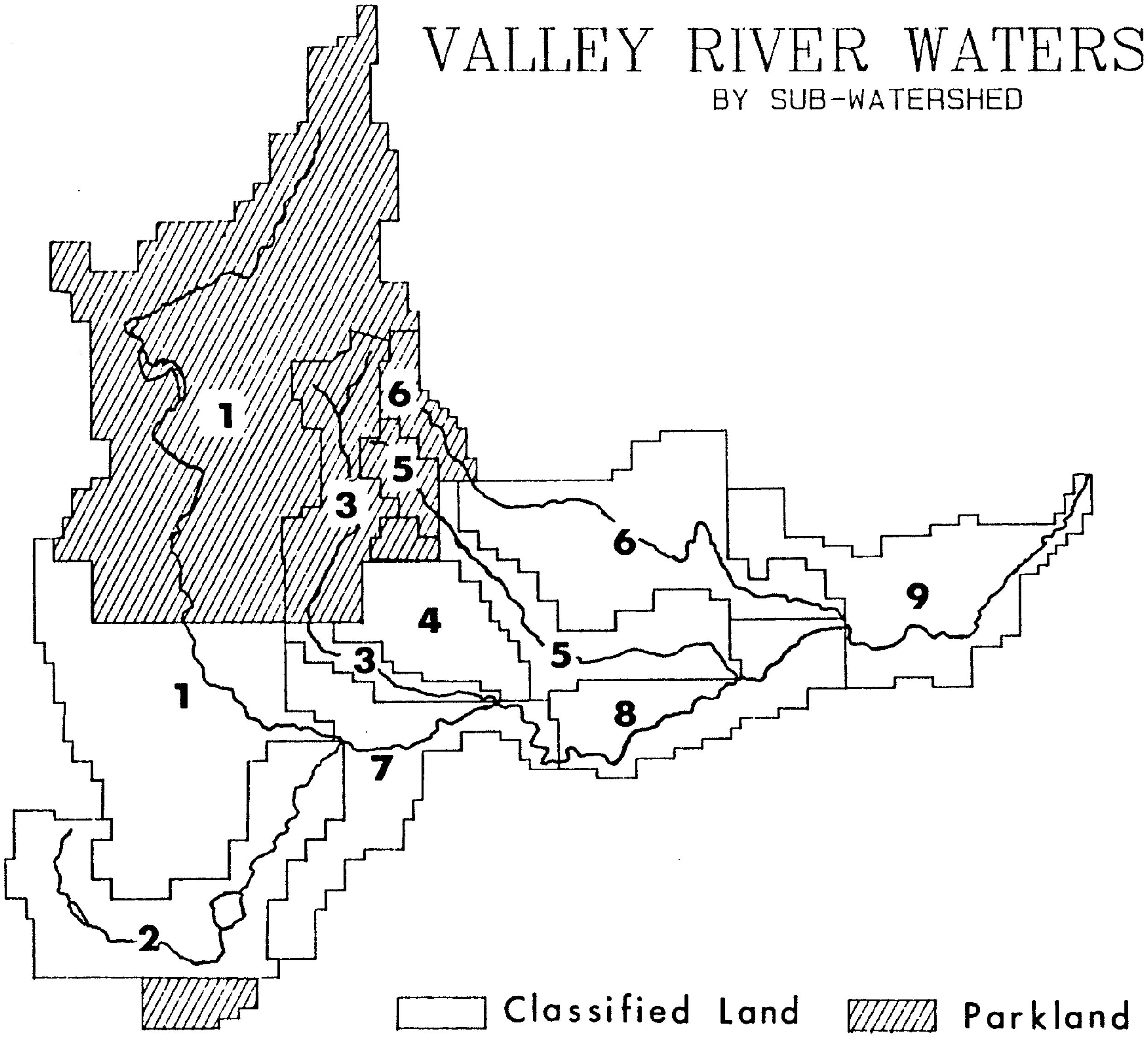


FIGURE 3.1 VALLEY RIVER WATERSHED

Figure 3.2

VALLEY RIVER WATERSHED

BY SUB-WATERSHED



forms part of the overall physical impact assessment of the watershed. The data were used for hydrologic modelling and trend analysis of other physical parameters such as sediment delivery and soil loss.

The Valley River watershed has large tracts of native forest and occupied agricultural areas that are not separated along drainage boundaries. In presenting the results, a distinction has been made between the study area, which is not defined along drainage boundaries, and the watershed area. The study area includes all the land in the Valley River watershed not inside Duck Mountain Provincial Forest and Park or Riding Mountain National Park boundaries. The data is presented by study area (1786 km^2), by total watershed and by sub-watershed. The sub-watershed division of data is needed to highlight changes in specific areas of the watershed.

3.1.1 Total Watershed Area

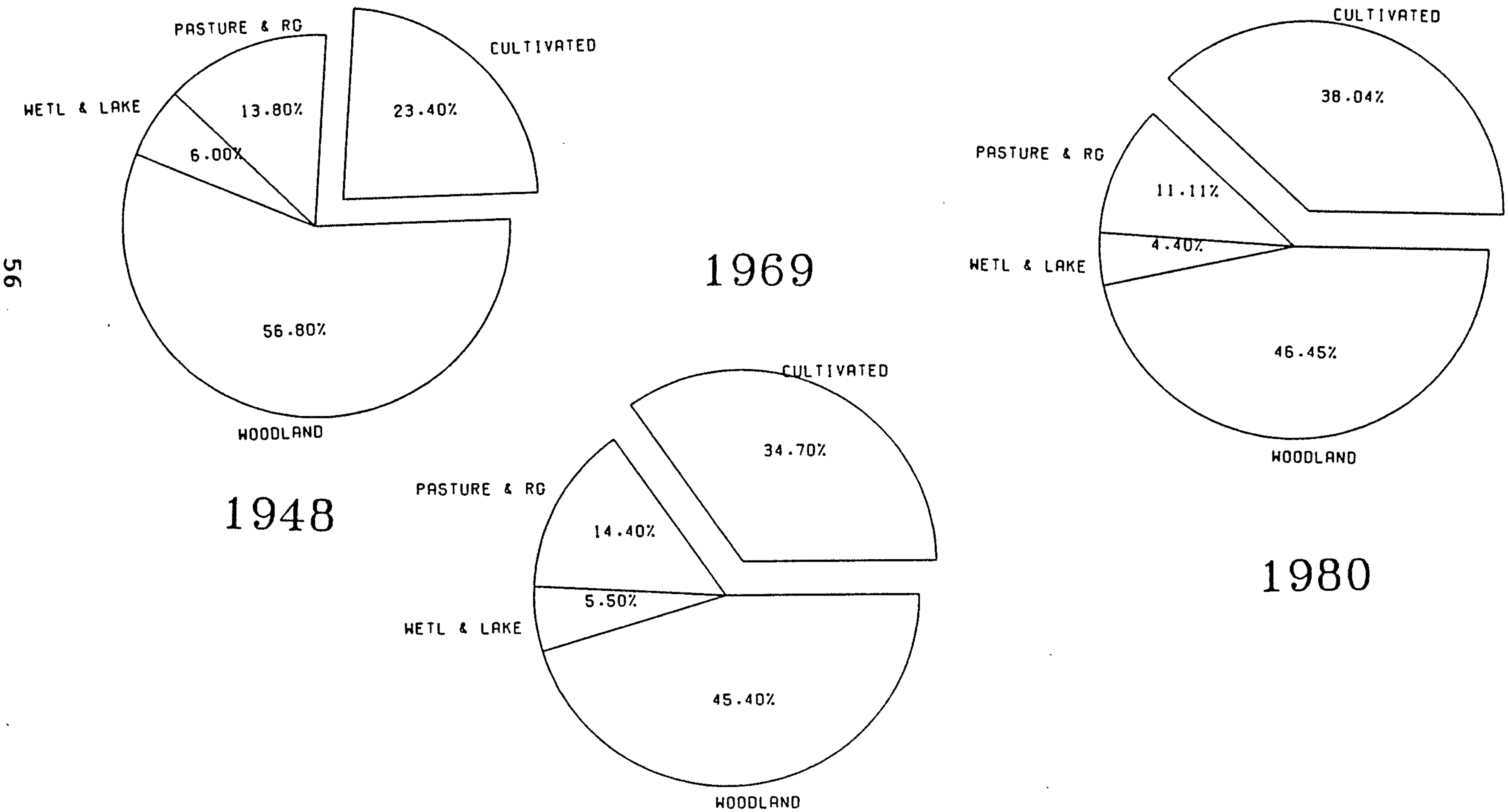
The Valley River watershed has 37% of its area in native forest. It was decided that detailed land use classification of this area which represents 1050 km^2 was unwarranted. When the land use information was compiled for the whole watershed the native forest area was assumed to contain 90% woodland, 5% wetland and 5% lake. The estimates are based on visual assessment of topographic maps of the area.

The data presented in this section does not include two land use categories indicated in Table 2.1. The urban and wasteland categories together were less than 0.1% of the watershed area and were therefore deleted. However, the figures for these two categories do appear in tables in Appendix 1.

The breakdown of land use for the three years is presented in Figure 3.3. The diagrams illustrate the large rise in cultivated land between 1948 and 1980. Cultivated land includes agricultural and summerfallow land (A and S). Cultivated land increased to 38% from 23% of the watershed. That represents 41385 hectares of land brought into production during the period 1948-1981 or 14.6% of the entire watershed. Cultivated land increased at a slower rate in the period 1969 to 1980 than the previous period. The potentially arable land became more scarce as agriculture development continued. Figure 3.3 also indicates that the increase in cultivated land is principally from woodland between 1948 and 1969.

Pasture land increased to 26,594 hectares in 1969 from 21,696 in 1948, but declined to 11,268 hectares in 1980 (Table 3.1). A possible cause of the large decline in pasture is overlap with the rough graze category. Table

Figure 3.3 Land Use On Total Watershed
1948 - 1980



3.1 indicates that when the two categories are grouped there is still a decline even though rough graze increased between 1969 and 1980. Between 1969-1980 some pasture land was probably converted to agriculture and some to woodland.

Table 3.1: Land Use for Total Watershed

Area = 283,562 hectares.

Land Use	1948 %	1948 ha.	1969 %	1969 ha.	1980 %	1980 ha.
1.Summerfallow	7.7	21730	11.1	31350	2.6	7266
2.Agriculture	15.7	44616	23.7	67053	35.4	100465
3.Pasture	7.7	21696	9.4	26594	4.0	11268
4.Rough Graze	6.1	17421	5.0	14277	7.1	20090
5.Woodland	56.8	160951	45.4	128834	46.4	131684
6.Wetland	3.4	9547	3.0	8540	2.0	5664
7.Lake	2.6	7365	2.4	6701	2.4	6881
8.Cultivated (Row 1&2)	23.4	66346	34.7	98403	38.0	107731
9.Total Improved Land (Rows 1,2&3)	31.0	88042	44.1	124997	42.0	118999
10.Rough Gr. & Past. (Rows 3&4)	13.8	39117	14.4	40871	11.1	31353
11.Wetl & Lake (Rows 6&7)	6.0	17294	5.4	15623	4.4	12927

Total Improved Land (TIL) includes cultivated and pasture land. In the period 1948-1969 TIL increased almost the same amount as cultivated land, but in the next period it declines while cultivated land was still increasing. The explanation for the decline in TIL is the loss of pasture-land as indicated in Table 3.1.

Summerfallow represented 32.8% of cropland in 1948, 31.% in 1969 and 6.7% in 1980. This reflects modern agricultural trend away from fallowing of land. The decline in the use of summerfallow actually began prior to 1969. It is believed that the decline began circa 1966 in Manitoba as a whole (Coote et al. 1983). The large decrease in summer-fallow in the more recent period also was observed on a province-wide scale, where summerfallow went from 20 to 12% of cropland between 1976 - 81 (Coote et al. 1983).

Woodland showed a decline of 10.4% of the watershed area or 32117 hectares between 1948-1969. Most of the cleared land became cultivated as Figure 3.3 shows. There was an increase in woodland from 45 to 46% of the area in the latest time period. The increase may be a result of maturing rough graze or abandonment of other land.

Wetlands and lakes declined as might be expected in an area primarily involved in agriculture. In 1948 this category represented 6% of the total area and in 1980 4.4%. Wetland showed the greatest loss, while the lake category actually increased in area between 1969-1980 (Table 3.1). A trend to remove potholes and fill in wetlands has been occurring in most agricultural areas. The farm equipment is now larger and less maneuverable and consequently wetlands and potholes are considered obstructions to cultivation. The desire to increase production also induces farmers to eliminate them from their land (Zittlau 1979).

In summary, the agriculture land category increased over time at the expense of woodland. Approximately 10.4% of the total watershed was cleared of woodland and 14.6% of the watershed was added to agriculture and summerfallow land use categories between 1948 and 1980. The earlier time period 1948-69 showed the greatest rate of change in land use when compared to the 1969-80 period.

3.1.2 Study Area

The actual study area represents that part of the watershed outside of Federal and Provincial Parks and Forests, and is therefore available for agricultural development. Land management is then restricted to this area. It is important to interpret the land use figures based on this area otherwise the significance of land use changes and trends may be missed.

The land use changes for the study area are presented in Figure 3.4. The trends in land use for the study area remain the same as described in the previous section, but the absolute quantity and relative proportion of land for each classification changes. This is because the data for the whole watershed includes an area of native forest that remains constant between the years of interest. Figures 3.3 and 3.4 illustrate the same trends in land use but the percentage of land use for each category has changed.

Cultivated land was 37.1% of the study area in 1948 and in 1980 it was 60.3%. (Table 3.2). This represents an increase of more than two thirds over 1948. Woodland accounted for 37.3% in 1948 and 20.8% in 1980; a loss of almost 18% of the whole study area. Again the land was primarily brought into agricultural production.

There was a loss in wetland and lake of 2.5% of the study area between 1948-1980. Wetland and lake declined from 6415 hectares to 2048 hectares , a decrease of more than three fold. However, the loss appears less severe when the whole watershed is considered. For the overall watershed the category declined by only one quarter of the total area in 1948 when compared to 1980. The study area has suffered a significant loss in wetland and lake but the watershed as a whole has only lost a moderate amount of this valuable resource.

Figure 3.4 Land Use On Study Area
1948 - 1980

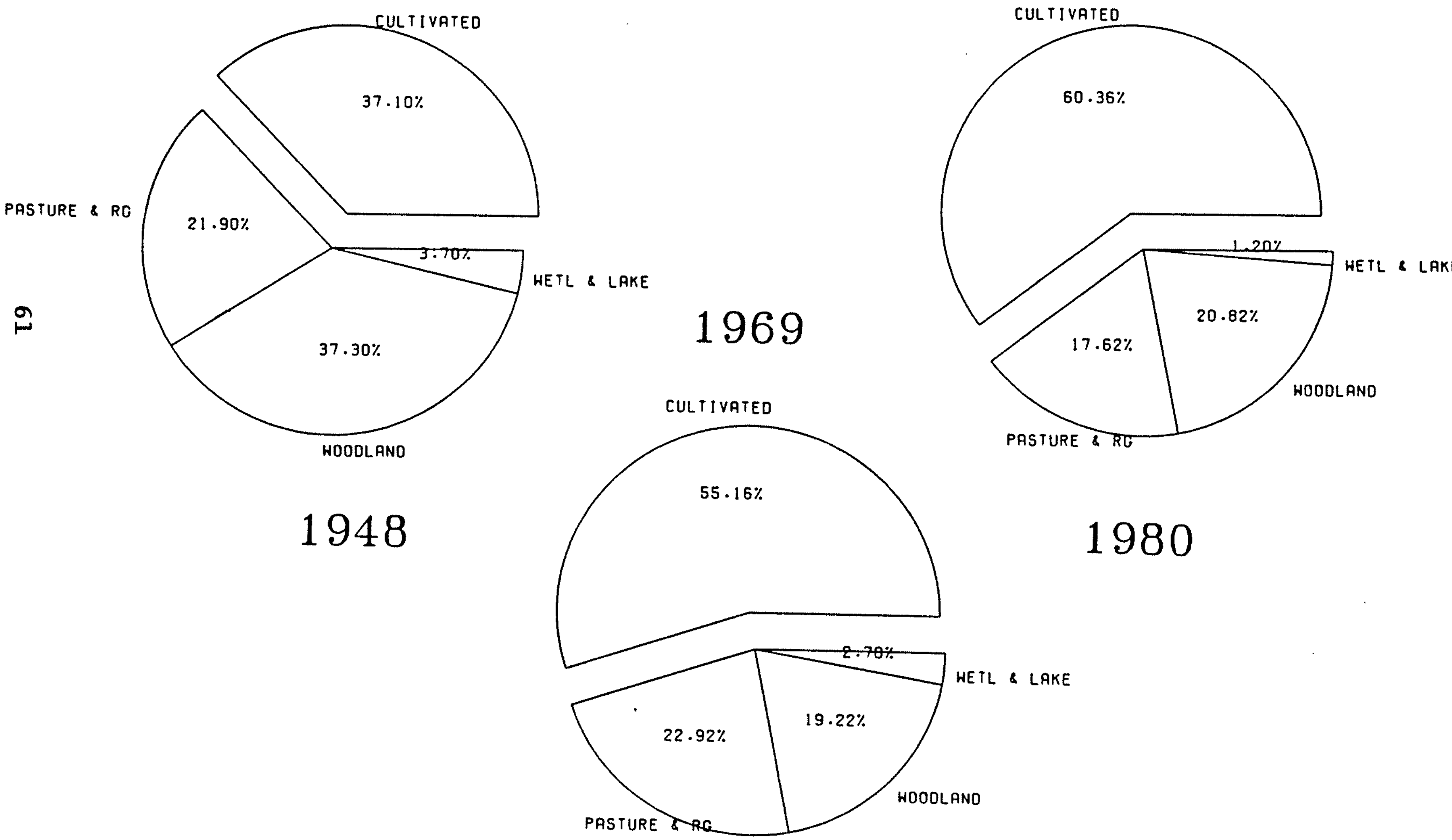


Table 3.2 **Land Use for Study Area**

Area = 178,600 hectares

LAND USE	1948 %	1948 ha.	1969 %	1969 ha.	1980 %	1980 ha.
1.Summerfallow	12.2	21730	17.6	31350	4.1	7266
2.Agriculture	25.0	44616	37.5	67053	56.2	100465
3.Pasture	12.2	21696	14.9	26594	6.3	11268
4.Rough Graze	9.7	17421	8.0	14277	11.3	20090
5.Woodland	37.3	66485	19.2	34368	20.8	37218
6.Wetland	2.4	4298	1.8	3292	0.2	416
7.Lake	1.2	2117	0.8	1453	0.9	1633
8.Cultivated (Row 1&2)	37.1	66346	55.1	98403	60.3	107731
9.Total Improved Land (Rows 1,2&3)	49.3	88042	70.0	124997	66.6	118999
10.Rough Gr. & Past. (Rows 3&4)	21.9	39117	22.9	40871	17.6	31353
11.Wetl & Lake (Rows 6&7)	3.7	6415	2.7	4745	1.2	2048

The wetland category alone showed a great loss between 1948-1980. Out of 4298 hectares in 1948 only 416 hectares remained in 1980 for a loss of 90.3% (Table 3.2). Most of this loss occurred since 1969. During the same period the lake category actually increased by 180 hectares. There may be some overlap in interpretation of land use categories that has magnified the results. The results, however, are indicative of a significant loss of wetland.

Many studies have demonstrated the general decline of wetland in agricultural areas (Adams and Genthe 1978, Rakowski et al. 1974, Kiel et al. 1972). Approximately 71% of prairie wetlands have been lost to agricultural development (Lands Directorate 1986). Wetlands were originally brought into agricultural production because they were viewed as potential productive land. Wetlands have also been drained in recent times due to economic pressures to bring every unit of land into production (Lynch-Stewart 1983). The environmental costs of wetland drainage are reductions in water quality, changes in magnitude and timing of stream flow, flooding, reduced baseflow, loss of vegetation and wildlife habitat (Lynch-stewart 1983).

It is interesting to note that similar significant losses in wetland have been documented for nearby areas. Studies in the Minnedosa pothole region have shown up to 40% decline in wetlands between 1964 and 1974 (Rakowski et al. 1974).

The 1980 land use analysis was performed on satellite imagery from 1980 and 1981, both of which were dry years. This, no doubt, contributed to the small area of wetland detected in 1980. However, drought contributes to the reclaiming of wetland for agriculture, since dry basins are exposed (Mann 1975). Therefore the loss of wetland may be over-estimated in the current study, but it could become a self-fulfilling estimate in future years.

In summary, of the land available for development, 31.3% was added to the agriculture category since 1948. The total area in this category rose to 56.3% by 1980. Woodland declined by 16.4% of study area for a loss of 29267 ha. Woodland occupied only 20.8% of the area by 1980. All the woodland cleared probably went into the agriculture category. There was 14465 ha. less summerfallow detected in 1980 than in 1948.

3.1.3 Comparison to Census Data

The census figures for the RMs of Dauphin, Gilbert Plains and Grandview show an average 33% increase in agricultural land between 1951 and 1971 as compared to a 50.3% increase for the Valley River between 1948 and 1969 (Table 3.3). The Valley River also had a greater increase in this category in the later time period 1969-80. The discrepancy between the census figures, which are partially inside the Valley watershed, and Valley River watershed data may be indicative of a greater quantity of desirable land for agri-development inside the basin than in the local municipalities. However, the census figures are based on occupied farm land not total land area. This may account for some of the observed differences.

Table 3.3 **Comparison of Census Data to Land Use Change**

RM or Watershed	Years	Percent Change: Agriculture	Pasture	Summer-fallow	Woodland
Dauphin	1951-71	24.7	59.7	20.2	-70.7
Grandview	1951-71	47.9	79.5	59.0	-39.9
Gilbert Pl.	1951-71	26.6	26.8	38.4	-69.5
Mean of RMs	1951-71	33.1	55.3	39.4	-60.0
Valley R.	1948-69	50.3	22.6	44.3	-48.3
Dauphin	1971-81	16.8	76.4	-21.9	7.0
Grandview	1971-81	13.8	4.5	-37.9	-15.1
Gilbert Pl.	1971-81	9.9	32.9	-36.0	-14.8
Mean of RMs	1971-81	13.5	37.9	-31.9	-7.6
Valley R.	1969-80	49.9	-57.7	-76.8	8.3

Summerfallow increased and decreased at a greater rate in Valley River than in the rural municipalities (RMs). This could be an anomaly caused by year selection or the time of year air photos were taken. Woodland decreased on farms through 1981, but on a watershed basis, woodland actually increased between 1969 and 1980 on Valley River.

The increase in woodland was probably due to abandonment of land or maturation of marginal land.

Generally, different results obtained from census figures illustrate the difference between basin studies and regional land data. This emphasizes the importance of watershed land use studies over the use of census data.

3.1.4 Sub-watersheds

The data for the this section was computed in two different ways as in the previous section. Computations were based on both the study area inside each sub-watershed and on the total area of each sub-watershed. Figure 3.2 illustrates the distinction between total area and study area within each sub-watershed.

3.1.4.1 Cultivated Land

The amount of cultivated (Ag and Sf) land in each sub-watershed is shown in Figure 3.5. Sub-watershed 7 had the greatest amount of its area cultivated in 1980 (73.6%). Sub-watersheds 8 and 9 showed the greatest increase in this category between 1948 and 1980 (Table 3.4). Sub-watershed 8 added 27.7% of its area or 6,292 hectares to the cultivated category.

Table 3.4 Cultivated Land Net Change
(In percent of watershed area)

YEARS	SUB-WATERSHEDS 1	2	3	4	5	6	7	8	9
1948-69	7.1	13.9	2.5	15.1	16.2	11.2	13.8	19.8	22.0
1969-80	2.0	0.8	1.4	1.3	2.7	10.9	0.7	7.9	2.4
1948-80	9.1	14.7	3.9	16.4	18.9	22.1	14.5	27.7	24.4

For comparison the percentage of each land use type was computed based on the study area part of the sub-watersheds (Figure 3.6). All the sub-watersheds have a substantial portion of their area under cultivation. The portion of the sub-watershed outside the study areas were not available for occupation or clearing and their inclusion in the computations masks the significance of some trends in land use.

Table 3.5 shows that sub-watershed 1 had the greatest increase in the cultivated land category when the area of the Provincial Park and Forest is removed from the calculation. Approximately 28.3% of sub-watershed 1 study area was brought into the cultivation between 1948-1980. Sub-watershed 1 also showed the greatest percentage increase in area of cultivated land when compared to the other sub-watersheds (Figure 3.7). Sub-watersheds 6 and 8 had the next highest increases in cultivated land.

Figure 3.5: Cultivated Land Use Change

on Total Watershed 1948 - 1980

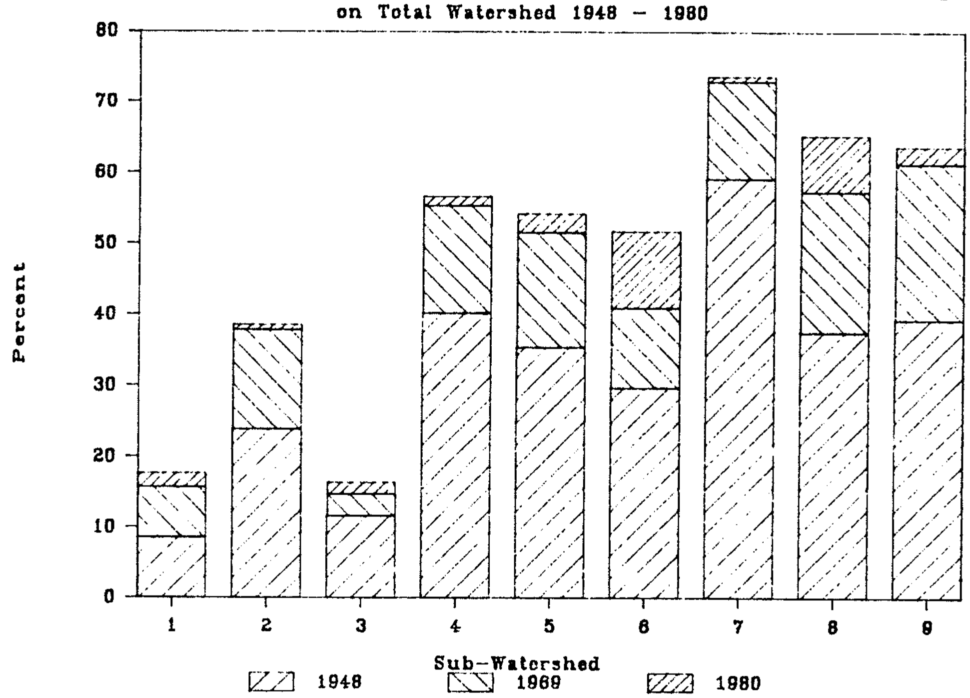


Figure 3.6: Cultivated Land Use Change

on Study Area 1948 - 1980

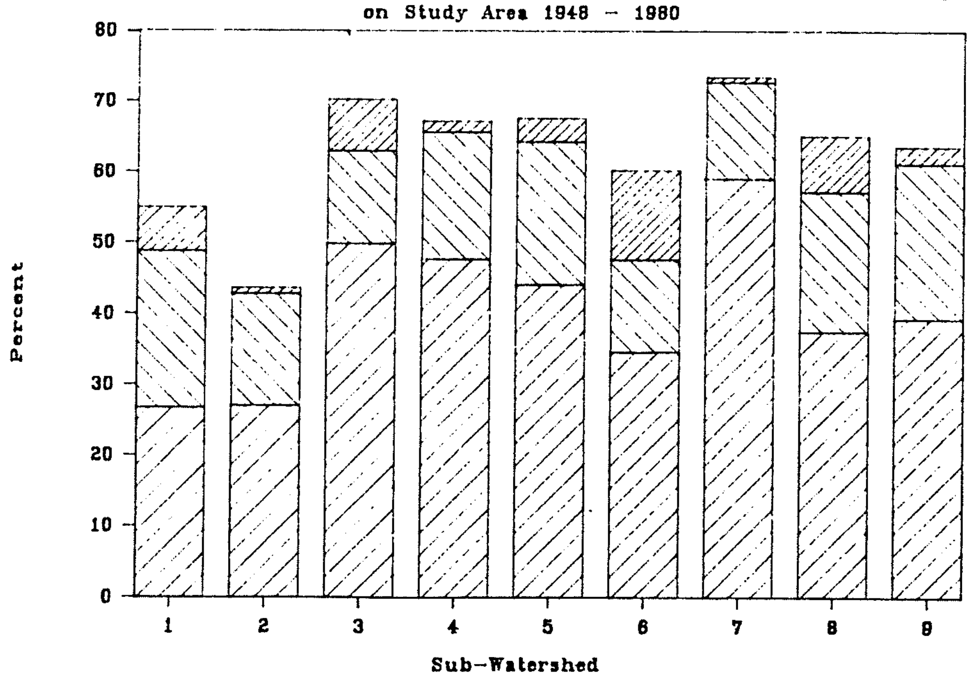


Figure 3.7

VALLEY RIVER WATERSHED

% CHANGE IN CULTIVATED AREA 1948-80

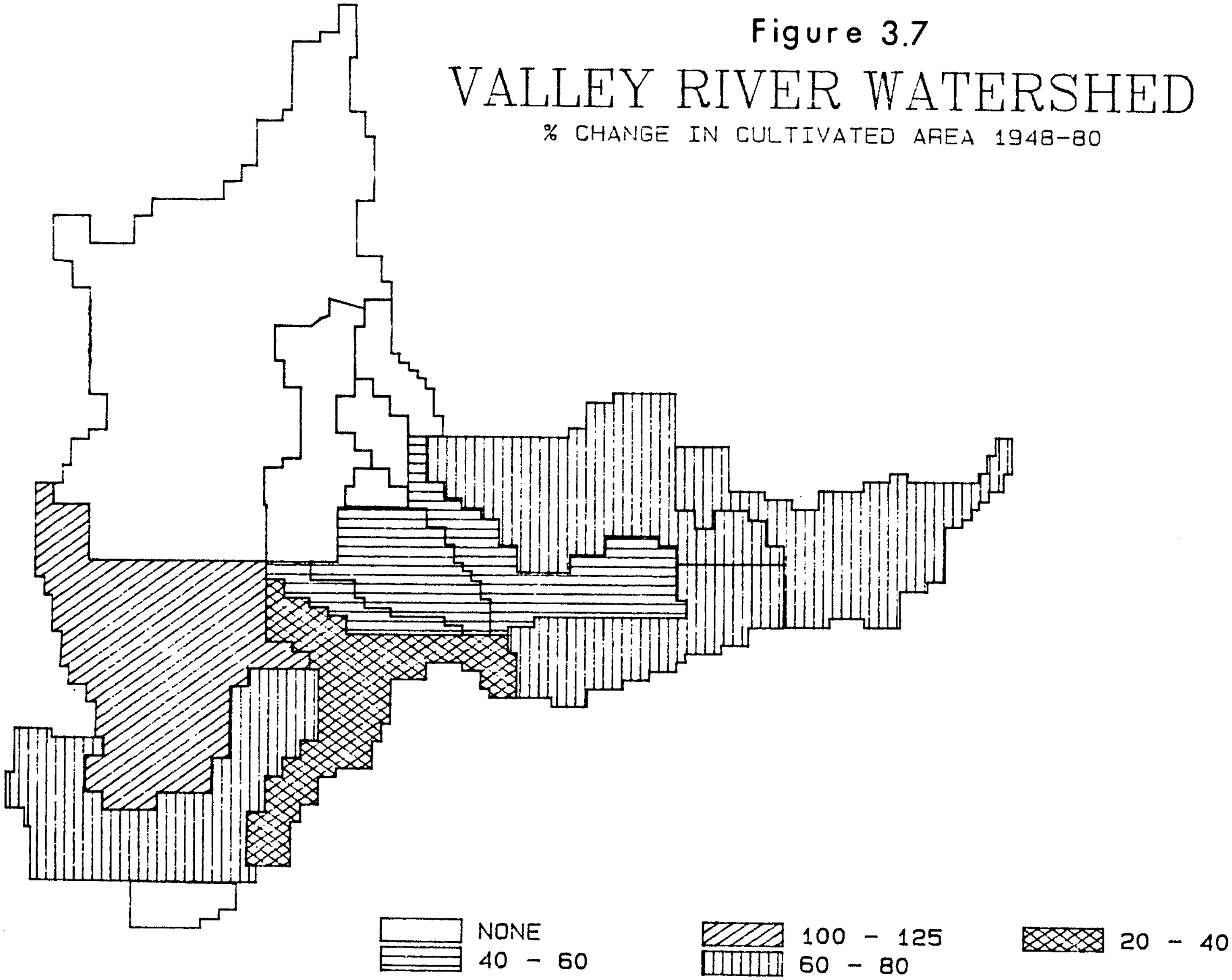


Table 3.5 Cultivated Land Net Change
(In percent of study area)

YEARS	SUB-WATERSHEDS 1	2	3	4	5	6	7	8	9
1948-69	22.1	15.8	13.1	18.0	20.2	13.0	13.8	19.8	22.0
1969-80	6.2	0.9	7.4	1.5	3.4	12.7	0.7	7.9	2.4
1948-80	28.3	16.7	20.5	19.5	23.6	25.7	14.5	27.7	24.4

3.1.4.2 Woodland

On a watershed basis, sub-watershed 1 and 3 had and still have the greatest amount of woodland (Figure 3.8). On the other end of the spectrum, sub-watershed 7 had the least amount of woodland in 1948 and a further 17.5% of the watershed was cleared by 1969. Only sub-watershed 6 had a greater loss of woodland in that period.

Sub-watersheds 4 - 9 had similar rates of woodland loss when Park land was removed from the calculations (Figure 3.9). All had between 15 and 21% of their classified area cleared. The mean loss of woodland for all the sub-watersheds between 1948 and 1969 was 18%. All sub-watershed except No. 4 had a slight increase in woodland between 1969 and 1980. The mean increase in that period was 1.8%.

Figure 3.8: Woodland In Watershed

In Percent Of Total Area

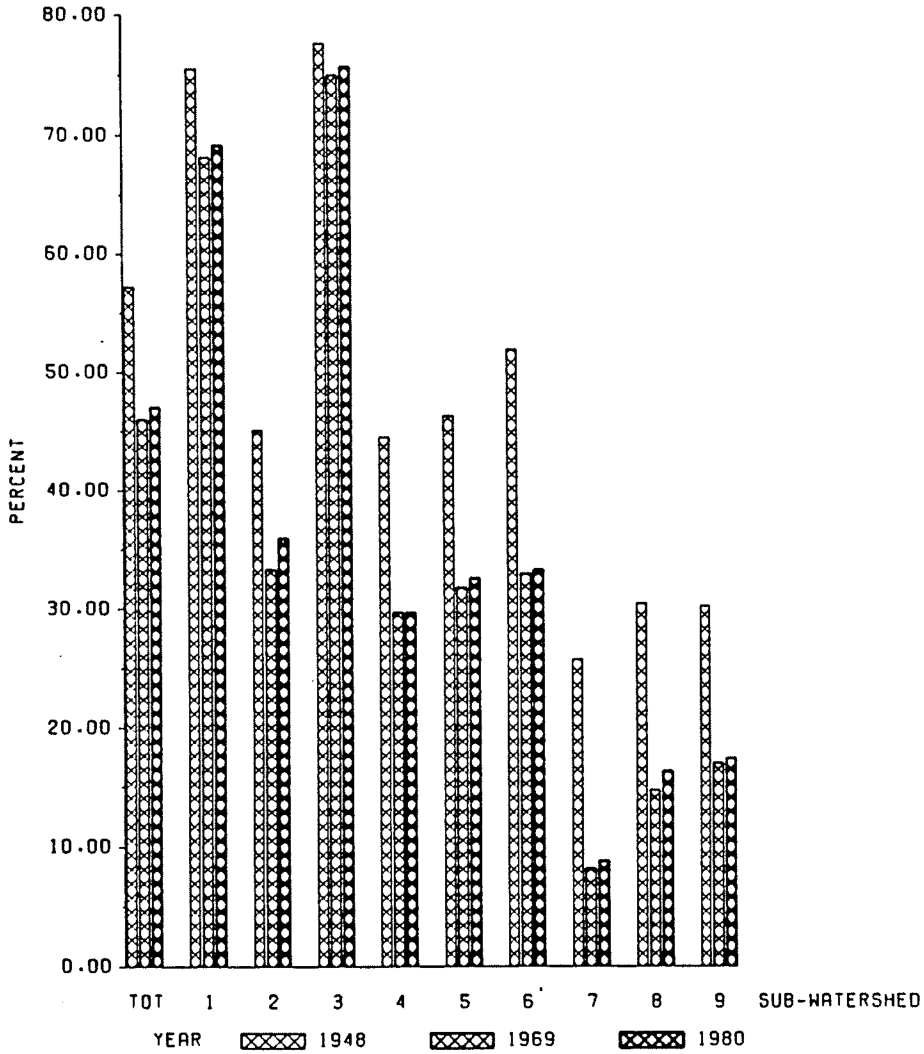
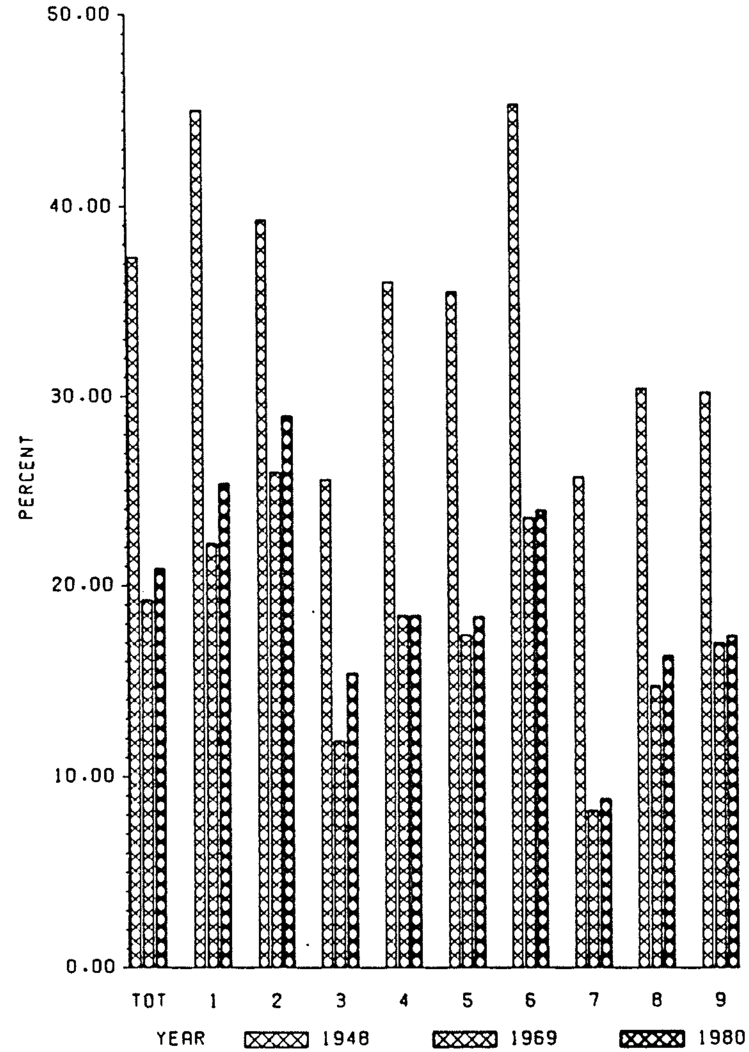


Figure 3.9: Woodland In Watershed

In Percent Of Study Area



3.1.4.3 Summerfallow

The practice of summerfallowing the land was highest in sub-watershed 7 between 1948 and 1969 (Figure 3.10). The decline in summerfallow between 1969 and 1980 was also highest in sub-watershed 7. Sub-watershed 5 had the highest use of summerfallow at 7.0% of the study area in 1980. Most of the sub-watersheds had between 3 and 7% of their area in summerfallow.

3.1.4.4 Wetland and Lake

The distribution of wetland and lake was investigated on a sub-watershed basis (Figures 3.11 & 3.12). What little wetland and lake there was in the study areas of sub-watersheds 4, 6, 7, and 9, was gone by 1980. The total loss of this category in these sub-watersheds may be the result of LANDSAT interpretation and/or the year of survey. Digital Analysis of the satellite imagery was least accurate on the wetland and lake categories, and was estimated to be 81% (Pokrant and Gaboury 1985). The LANDSAT imagery used in the analysis was recorded on August 23, 1981 and July 13, 1980. Both these summers were very dry in Valley River watershed. However, the severe reduction, if not total loss of wetland in 4 out of 9 sub-watersheds is disturbing and

Figure 3.10 Summerfallow in Watershed
In Percent Of Study Area

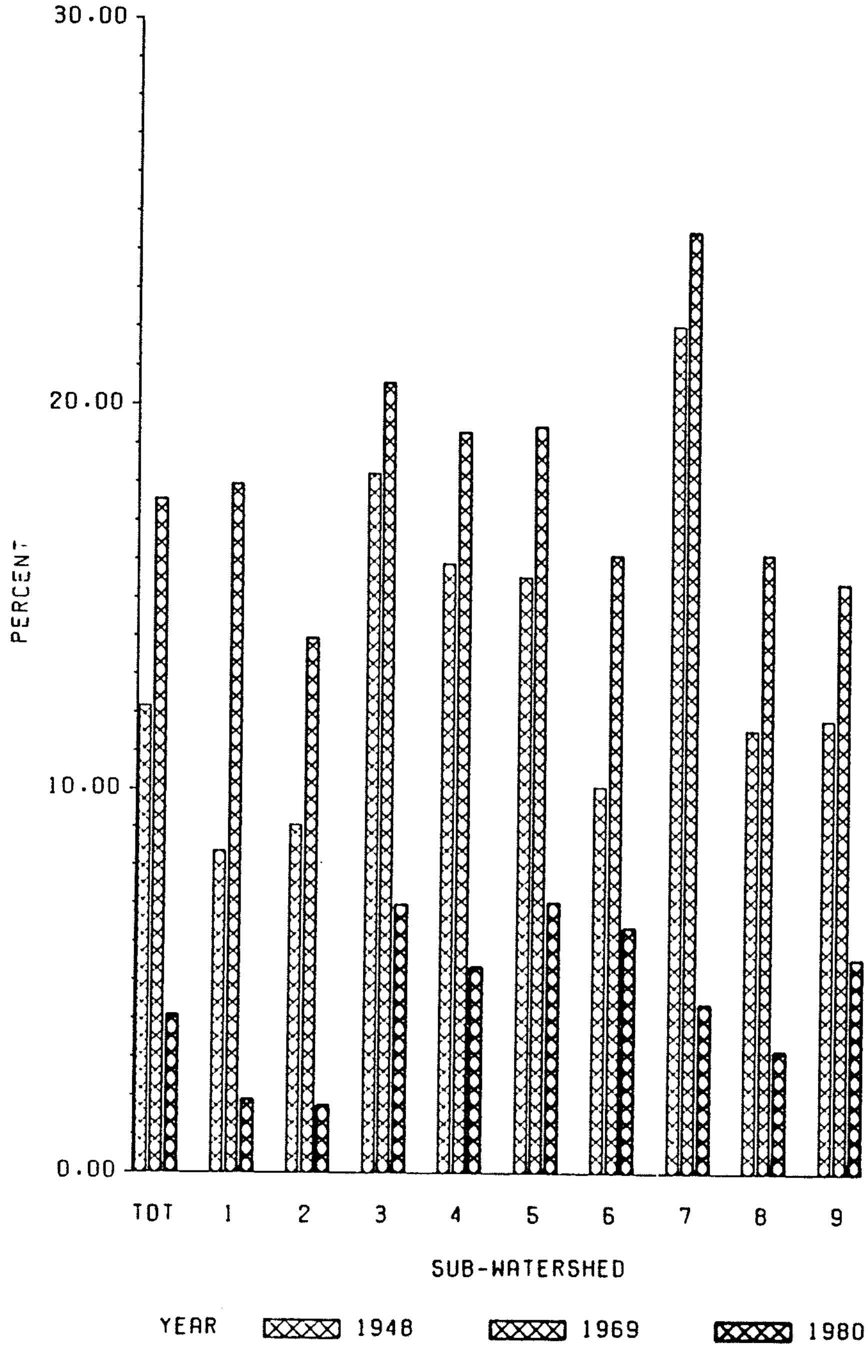


Figure 3.11 Wetland And Lake In Watershed
In Percent Of Total Area

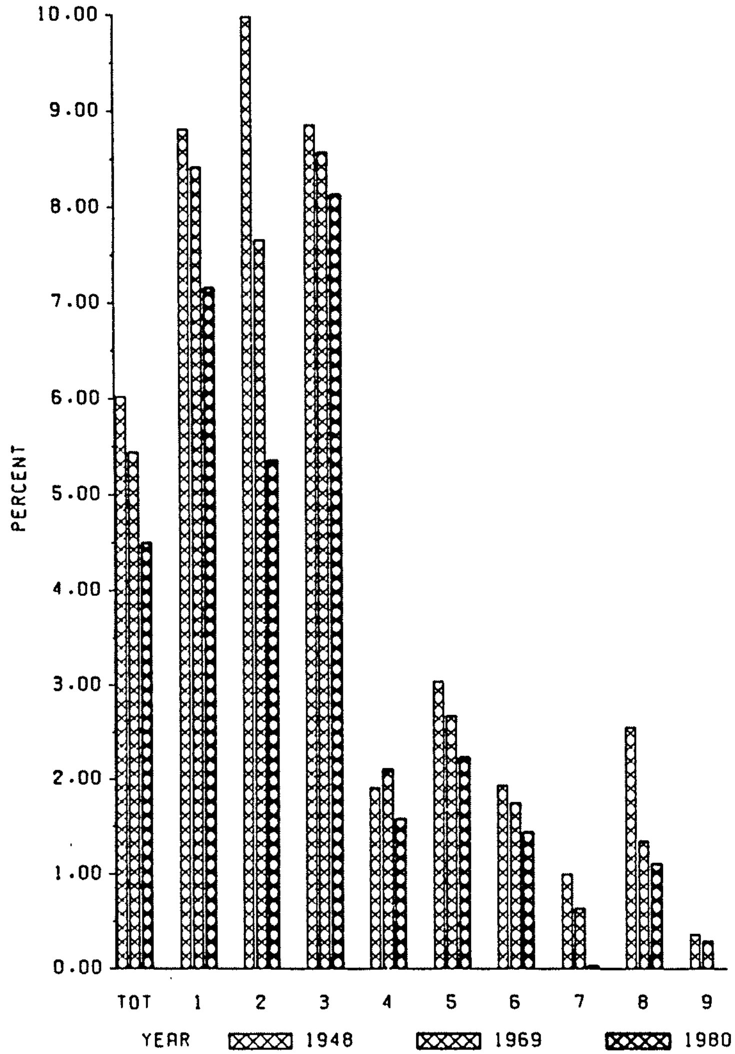
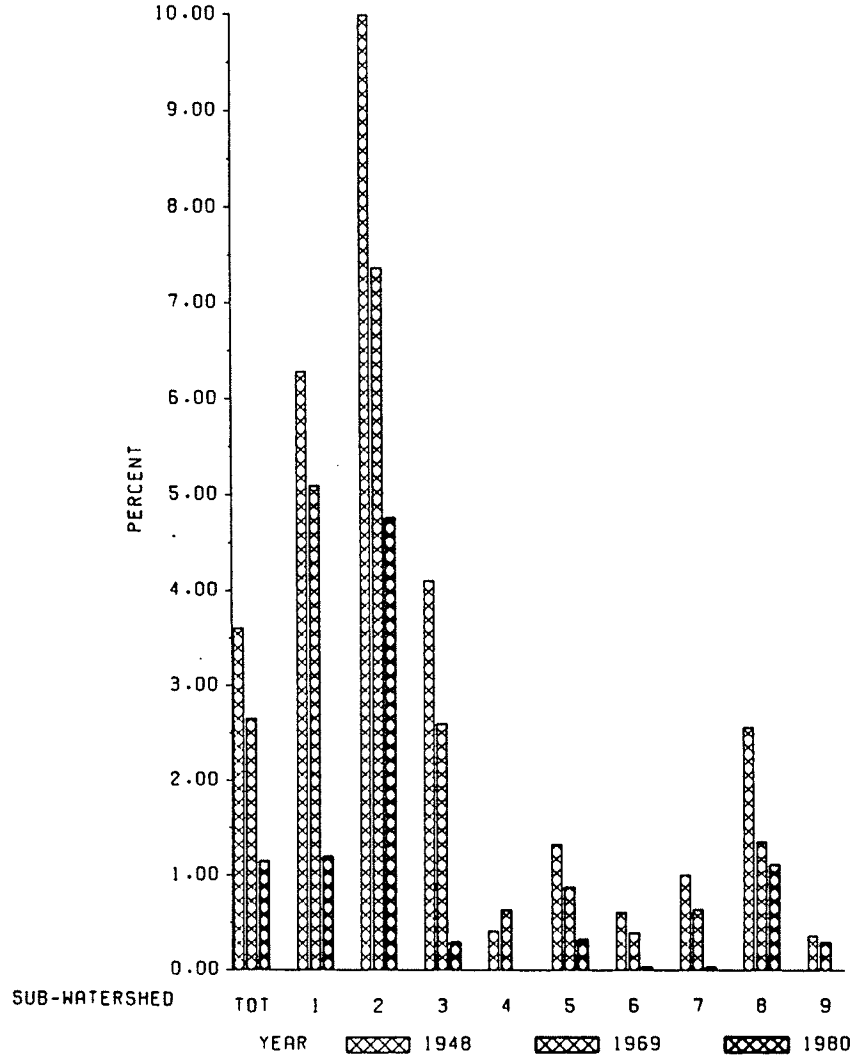


Figure 3.12 Wetland And Lake In Watershed
In Percent Of Study Area



is likely to have serious impacts on the hydrologic regime of the watershed.

The greatest single loss of wetland occurred in sub-watershed 2. Between 1948 and 1980, 1575 hectares (5.9% of the study area) was lost. Most of the wetland-lake losses occurred since 1969, whereas most land clearing occurred prior to 1969. The trend towards bigger equipment and maximizing land use probably caused the losses since 1969.

In summary, sub-watershed 7 showed the greatest impact of agri-land development. It had the largest percentage of area under cultivation and in summerfallow, the greatest loss of woodland, and the total loss of wetland. Sub-watersheds 8 and 9 were the next most heavily developed for agriculture. The changes in land use/cover increased, with progression in a downstream direction.

3.1.5 Riparian Land Use

The riparian zone of a stream is often called a buffer zone. The strip of land on either side of a stream mitigates erosion and soil loss processes that occur as a result of upland development. Removal of the cover vegetation in the this zone can have serious ecological consequences instream.

Streamside vegetation is a source of food, shelter and protection for the stream community (Mahoney and Erman 1984). Leaves, leaf litter, twigs and other detrital matter are a source of energy for stream biotic communities. Riparian vegetation also acts as a substrate for production of invertebrates which are an important source of fish food. In headwater areas, riparian vegetation is the most important source of energy and its removal can alter the food web and species composition of a stream (Schlosser and Karr 1980).

Riparian vegetation provides shade which modifies stream water temperatures, and temperature is an important habitat constraint on fish and invertebrates. Species composition of streams can alter in response to wide temperature variations caused by vegetation removal. This is because metabolic rates and chemical reactions are dependent on ambient water temperature (Knight and Bottorf 1984).

Riparian vegetation creates bank and soil stability which reduces bank and channel erosion and prevents sediments from entering the stream. Land use activities on valley slopes that increase runoff and soil loss, such as cultivation, may have a reduced impact on the stream if there is a buffer strip of vegetation present along the stream bank. Stream side vegetation filters sediments and contaminants attached to soil particles before they reach the stream.

Water patterns can change in response to riparian vegetation removal especially when surface runoff increases. This can cause the stream channel to readjust velocity patterns, channel dimensions, frequency of pools and riffles, and substrate composition. These parameter changes are the main determinants of fish habitat. Species composition and abundance changes as a result of such alteration of habitat. Species diversity often declines especially if fine sediments are added to the stream.

In summary, the effects of vegetation removal in the riparian zone are: 1) loss of detrital inputs; 2) loss of shade; 3) water quality/quantity changes; 4) loss of terrestrial habitat (Knight and Bottorf 1984).

3.1.5.1 Valley River Riparian Zone

The Riparian area along the mainstream of the Valley River was investigated for land use changes between 1948 and 1981. Air photo interpretation was used to detect the changes in the riparian zone. The analysis covered an area of 6471 hectares for both 1948 and 1981. The area covered corresponded to the visually interpreted flood plain along the main stem of the Valley River (Figure 3.13).

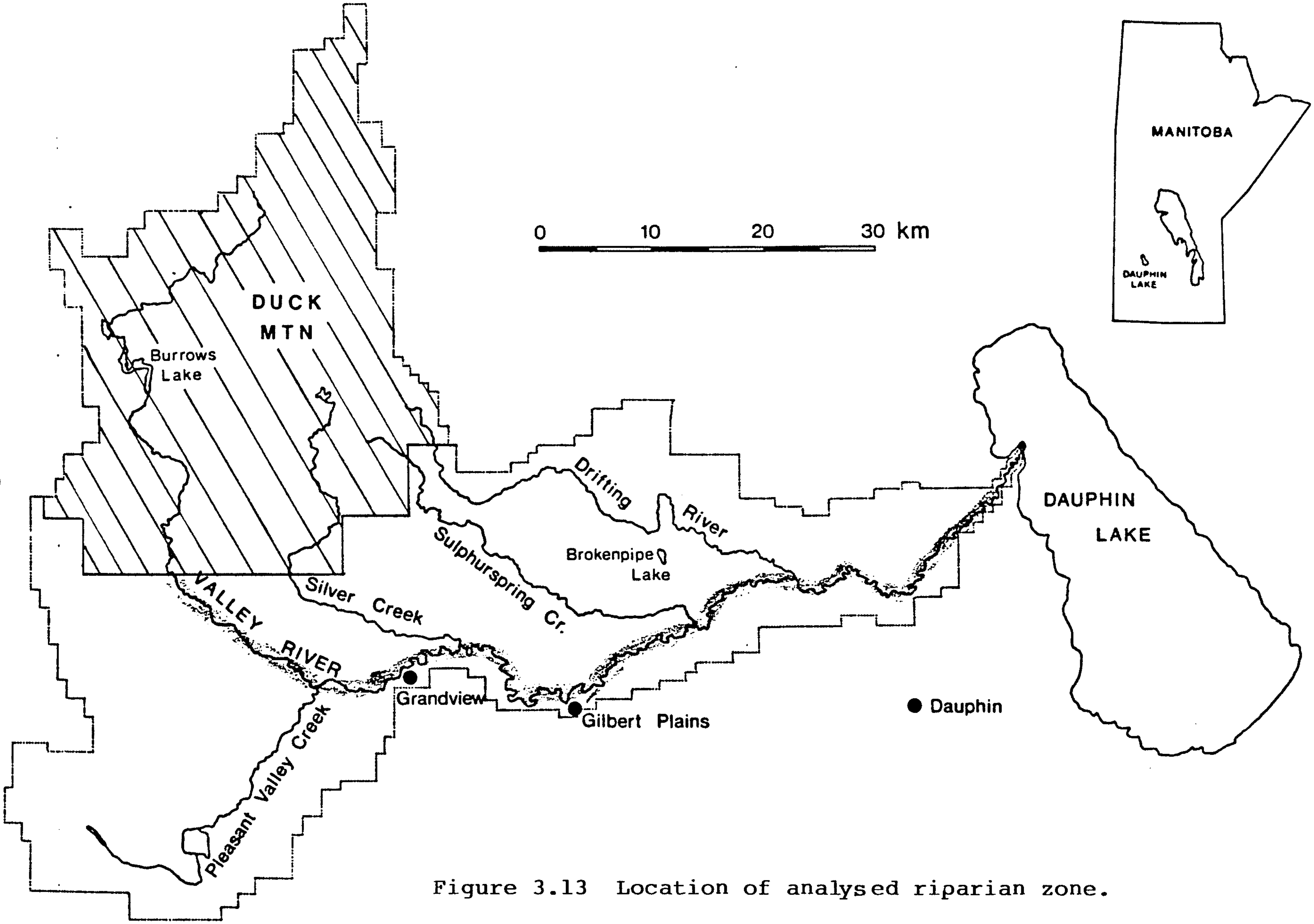


Figure 3.13 Location of analysed riparian zone.

Woodland decreased by 21.2% from 1948-81 and only accounted for 47% of the total area versus 60% in 1948. Agricultural land increased to 22.4% and summerfallow to 10.3% in that period.

The cultivated land accounted for 32.7% in 1981 compared to 16.9% in 1948 (Figure 3.14). Total improved land (TIL) increased from 1835 ha. to 2720 ha. for an increase of 48%. In the same period 90% of the wetland was removed. Wetland went from 120 ha. in 1948 to 11 ha. in 1981.

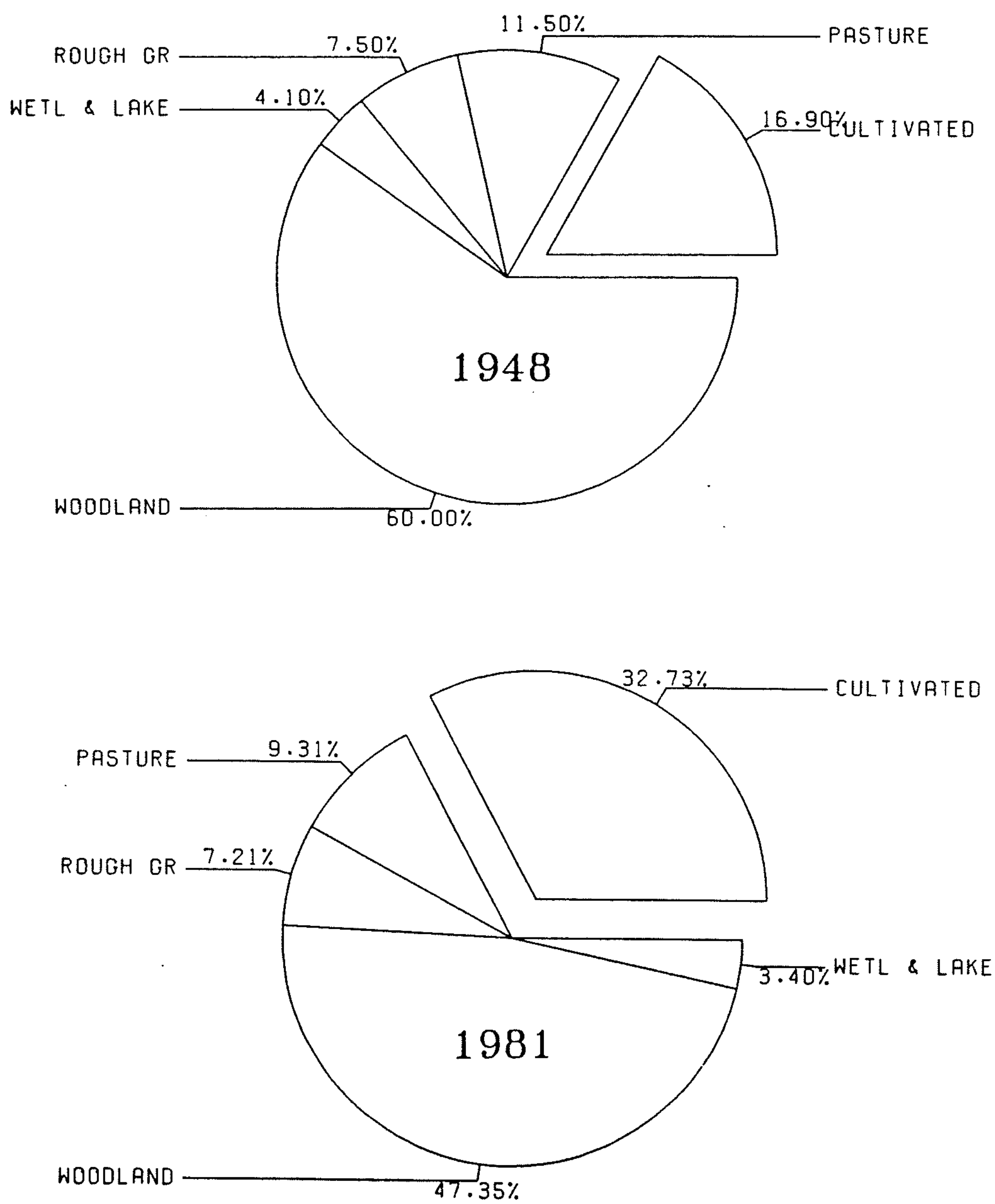
The steady increase in development in this zone may contribute to serious soil loss and sediment problems. The air photos showed many areas along the river where land was cleared to the water's edge and/or cleared below the high water mark. Cultivation on flood prone land was also accompanied by the practice of summerfallowing, which could result in a serious loss of top soil in a high runoff year.

In summary, the riparian strip lost 822 ha. of woodland and gained 699 ha. of agriculture between 1948 and 1980. Approximately 10.8% of the area was cleared for agriculture. Summerfallow nearly doubled in area to 5% of the land in the zone.

3.1.6 Significance

Land use changes also impact water quality and quantity. Hydrograph analysis on the Valley River has shown

Figure 3.14 Riparian Land Use



the changes that have occurred over time in surface runoff, peak flow and time of concentration (Sec. 3.2). These hydrologic changes are directly related to land use and management, and lead to fish and wildlife habitat degradation.

The significance of land use changes, especially in the riparian zone, could contribute to a reduction in stream fish diversity and abundance. A study on two tributaries of the Valley River in 1983 demonstrated changes in species diversity and composition (Gaboury pers. comm.). Silver Creek was relatively undeveloped while Pleasant Valley Creek was heavily developed for agriculture. Silver Creek had a greater species diversity and abundance than Pleasant Valley Creek.

3.2 HYDROGRAPH ANALYSIS

The shape of a hydrograph is characterized by the physical and geological properties of the upstream watershed and the temporal and spatial distribution of storm rainfall. It is also a function of land use on the watershed. Changes in land use are often reflected in the runoff hydrograph shape. Land use analysis on the Valley River watershed indicated a significant increase in land clearing and agri-development since 1948. The historical spring runoff hydrographs were analysed on the Valley River to determine if any change had taken place.

Land clearing and drainage often leads to increased runoff and peak flow rate. The clearing of land reduces infiltration capacity because there is less removal of water from the root zone. Vegetation removal also reduces interception and evapotranspiration losses. This results in an increased volume of runoff. Runoff is often faster over exposed soil than treed areas due to reduced roughness of the landscape with subsequent increases in surface runoff velocities. Land drainage can increase the volume of runoff and also the speed. This can lead to increased peak flow rates and rapid attenuation of flows. The effect on the surface runoff hydrograph shape a is shorter time to peak (Tp), faster ascending and recession limbs and greater peak flows. These effects were examined by analysing all available runoff hydrographs for Valley River.

3.2.1 Normalized Hydrographs

A plot of normalized data for the three time periods, 1913-28, 1948-1964, and 1965-81, showed the earlier period to have a shallower recession limb (Figure 3.15). The normalized discharges were higher, post peak, for the 1913-28 period, than the other two periods. The 1913-28 hydrograph also showed a slower ascending limb up to 3 days before peak, than the other periods. The latest period, 1964-81 tended to have the fastest rising and descending limbs. Similar conditions were observed for the 1948-63 period, although it was not as evident on the descending side. It should be noted that the pre-peak flow data were not as reliable as the post-peak data due to measuring techniques in earlier times when water level recording did not begin until a few days before peak spring flow.

Since the preceding analysis indicated a significant difference between the earlier time period and both subsequent periods, a further test was performed on the data. The data were divided into two time periods instead of three, sorted to eliminate double peaked hydrographs, and plotted. Only 9 years were left in each of the two time periods after sorting (Figure 3.16). The normalized hydrographs produced clearly separated the two time periods by hydrograph shape.

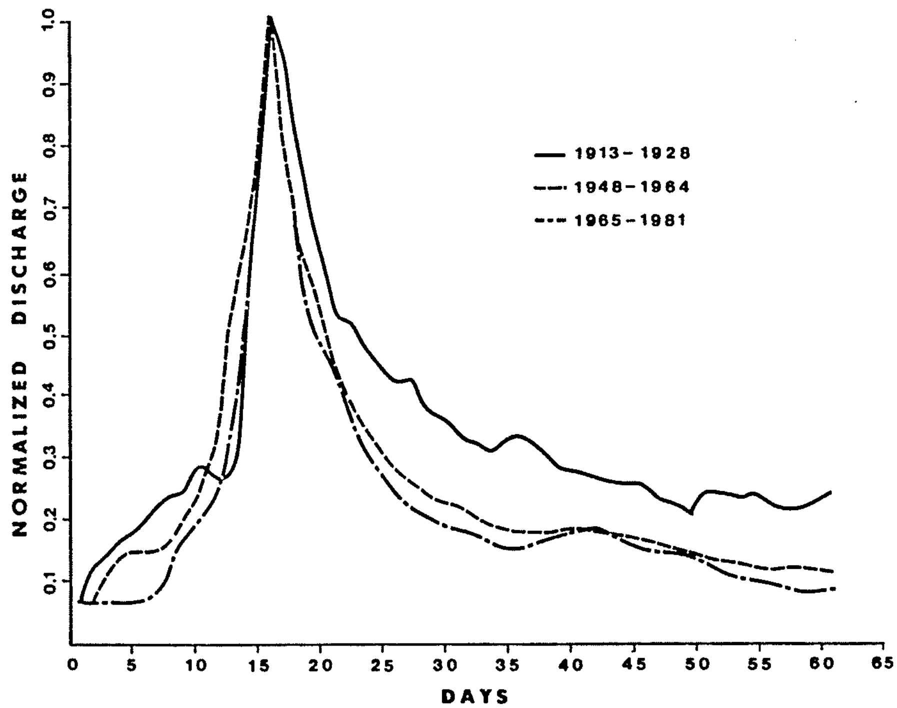


Figure 3.15 Normalized spring runoff hydrographs 1913-81.

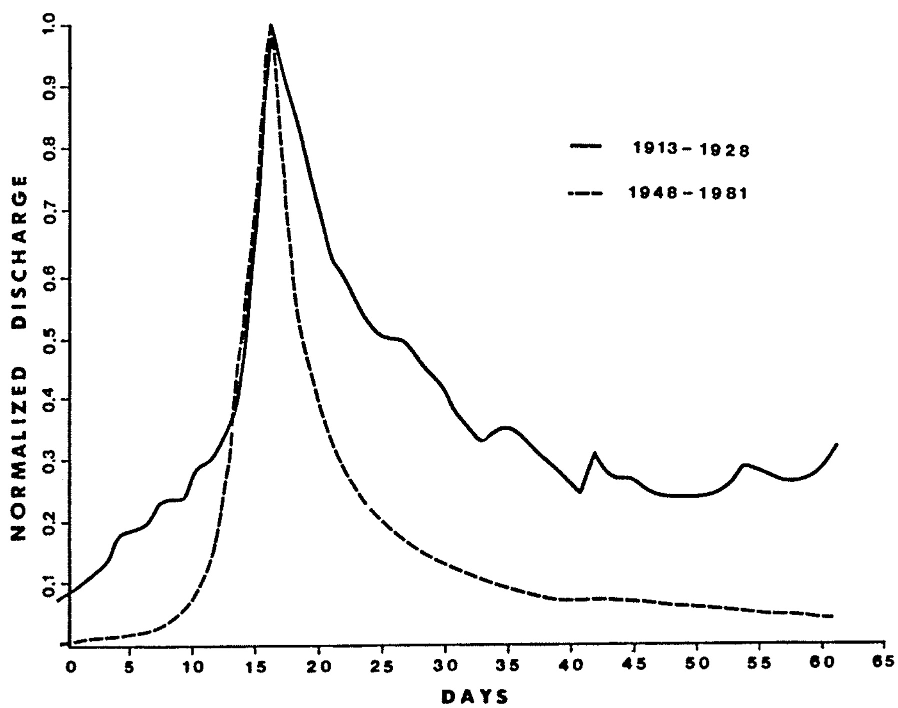


Figure 3.16 Normalized spring runoff hydrographs, selected years.

The latest period 1964-81 had faster time to peak and a steeper recession limb which means rapid attenuation in flows following the peak flow rate. The variation in the shape of the hydrographs even after the separation is strong evidence of significant change in the hydrologic regime which may have resulted from the clearing and drainage of land.

3.2.2 Odd/even Analysis

Odd-even analysis was performed on the runoff data. The 1948-81 period showed some variation between even and odd years, as did a similar plot for the 1913-28 period (Figures 3.17 & 3.18). The variation **between** odd and even years for the time periods was less than **among** time periods (Figure 3.19) which makes it unlikely the observed result in Figure 3.16 was a product of anomalous data. A plot of even and odd years for all the historic flow record showed a fairly close relationship (Figure 3.20). The greatest variance was from 0 - 10 days on the pre peak side of the graph. The recession limbs were in very close agreement which adds further strength to the observed results in hydrograph divergence over time.

3.2.3 Averaged Hydrographs

A comparison of averaged hydrographs for the 3 time periods showed the earlier period with a lower peak flow

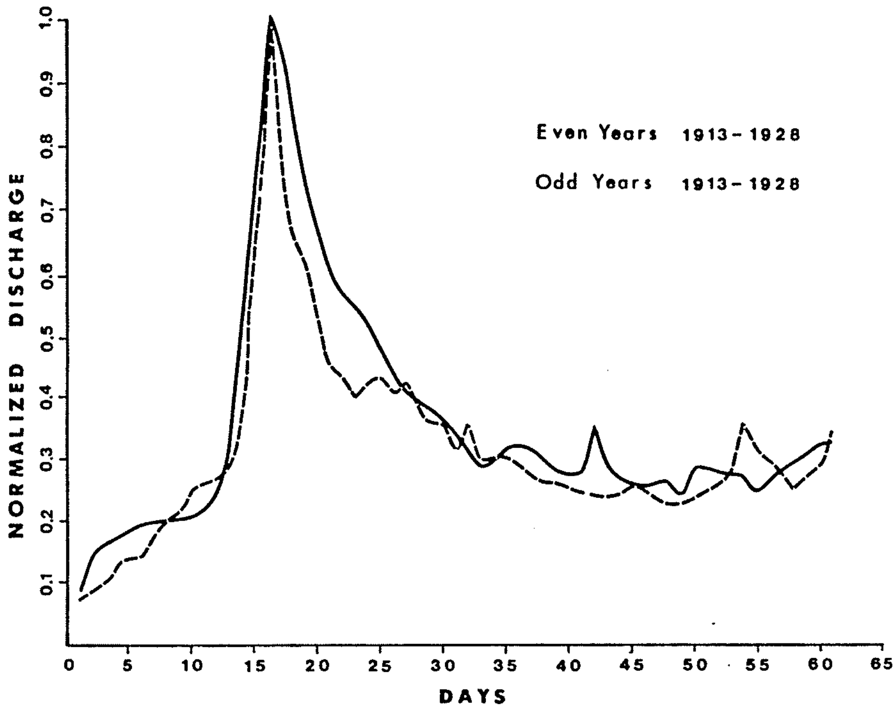


Figure 3.17 Odd/Even analysis of spring runoff hydrographs 1913-28.

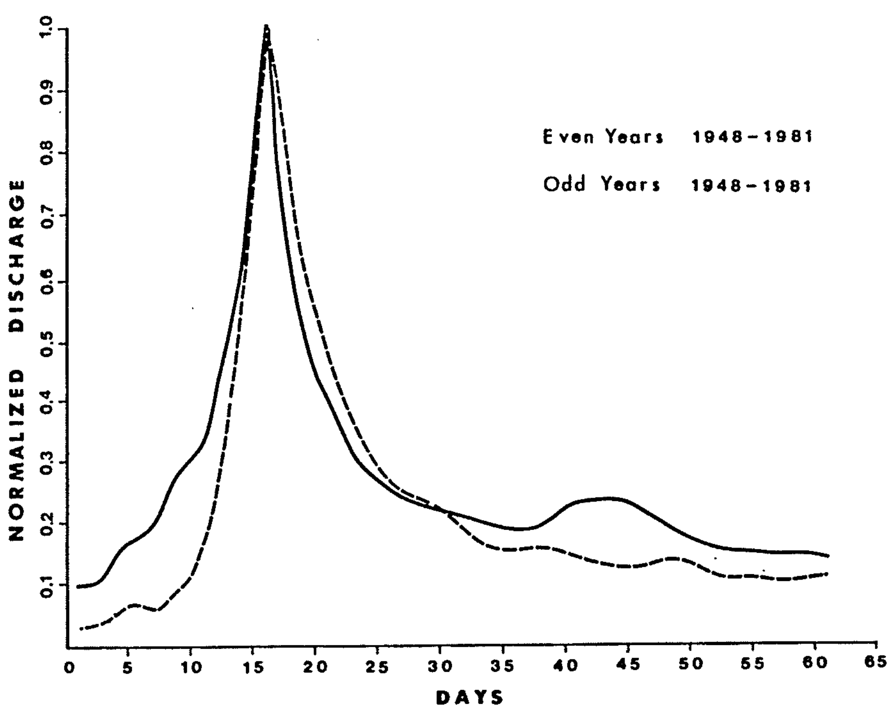


Figure 3.18 Odd/Even analysis of spring runoff hydrographs 1948-81.

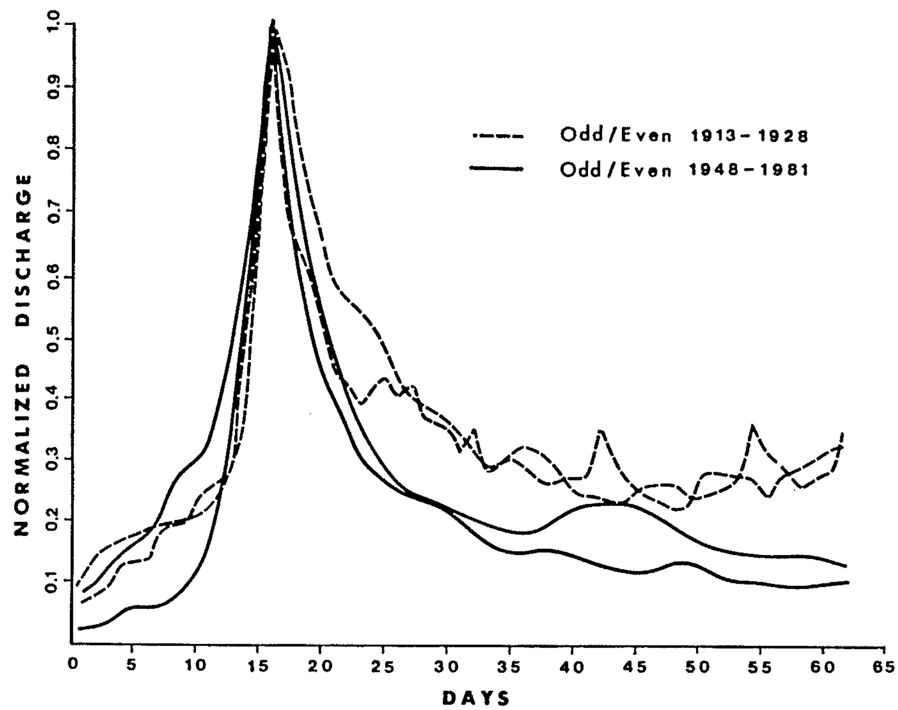


Figure 3.19 Odd/Even analysis on spring runoff hydrographs 1913-28 and 1948-81.

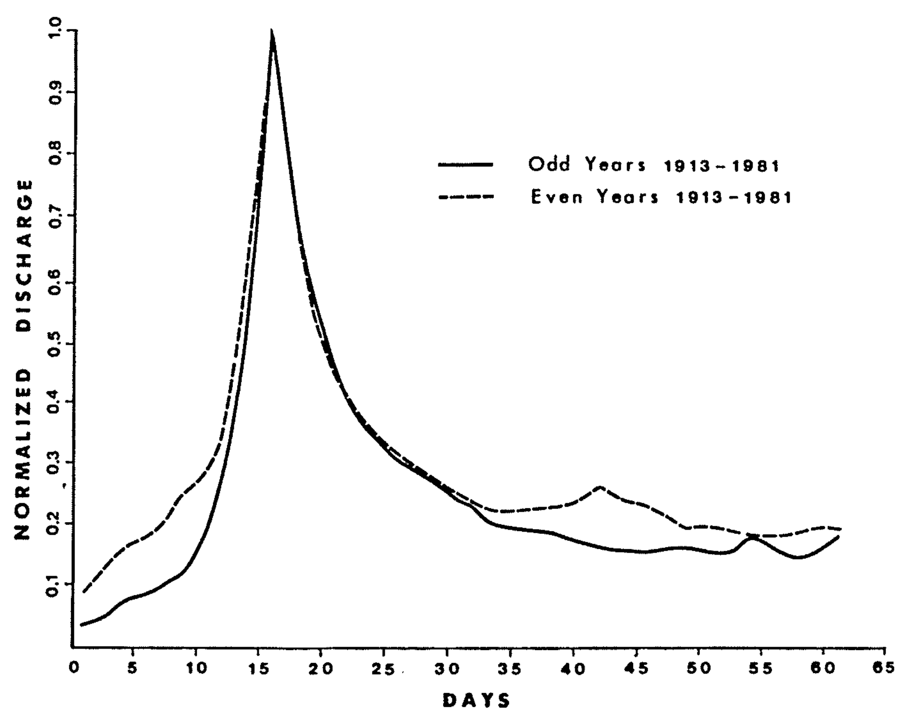


Figure 3.20 Odd/Even analysis on spring runoff hydrographs 1913-81.

rate and shallower recession limb (Figure 3.21). The results may in part be due to precipitation patterns or other climatic factors.

Factors affecting runoff and peak flow were calculated as far back as 1948 to evaluate their impact on the spring runoff hydrograph (Table 3.6). The factors were: total winter precipitation (TP), antecedent precipitation index (API), melt index (MI), and runoff volume (RO). Averages for these parameters were calculated for the two most recent time periods 1948-63 and 1963-1981. Average winter precipitation, TP, was 1.9% greater in 1964-81 period but RO was 5% greater. API was 14% higher in the latter period which could account for the difference between periods.

Table 3.6: Average Climatic Factors.

Years	TP (mm)	API (%)	MI Deg-D	RO (mm)	PEAK (m^3/sec)	RO/TP
1948-64	134.4	96.9	6.447	23.0	55.3	0.171
1965-81	136.9	110.7	5.071	24.1	91.0	0.176

Peak flow rate was 65% higher between 1964-81 than the previous period. MI was only 21% higher on average in the latest period and therefore the increase in peak flow rate may not entirely be accounted for by climatic factors. The large increase in peak flow rate combined with an increase in runoff and runoff ratio (RO/TP) indicates the

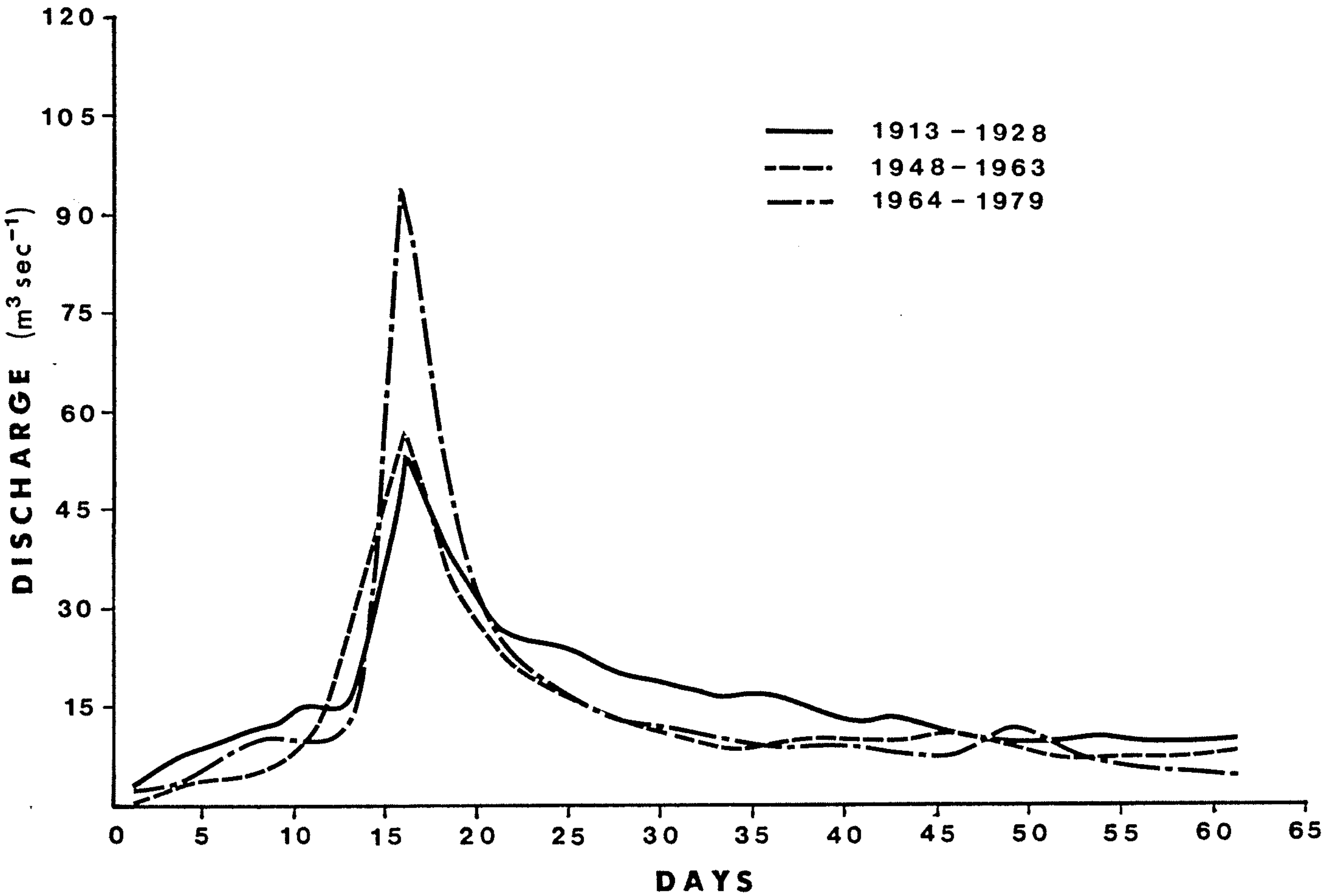


Figure 3.21 Averaged Spring Runoff Hydrographs 1913 - 1979.

possibility of a change in hydrograph shape. Similar comparisons could not be made for the 1913-28 period because of insufficient data.

Given the magnitude of the differences between the averaged hydrographs it is likely that at least some of the difference arises from non climatic factors. Changes in land use may have contributed to the observed differences. Since 1948 41385 hectares were brought into cultivation, representing 23% of the watershed outside the Provincial Parks and Forest. The percentage of the watershed under cultivation went from 37% in 1948 to 60% in 1981.

A further check on relative peak flow and magnitude was done by dividing each day's discharge by the total discharge for a 60 day period after the peak flow date. The results were then averaged for each time period as in previous graphs (Figure 3.22). The 1913-28 time period had the smallest proportion of total discharge occurring as peak flow. The 1913-28 period had 4.8% of total discharge as peak flow, while the 1964-81 period had 11.0%. The recession limbs of the graph were steeper for the two later periods than the earlier period. The graph indicates that the magnitude of the peak flow rate, and the speed of spring runoff has increased over time.

The average adjusted hydrographs for each period show a clear separation in their recession limbs (Figure 3.23). The most recent period, 1964-81, had the steepest recession

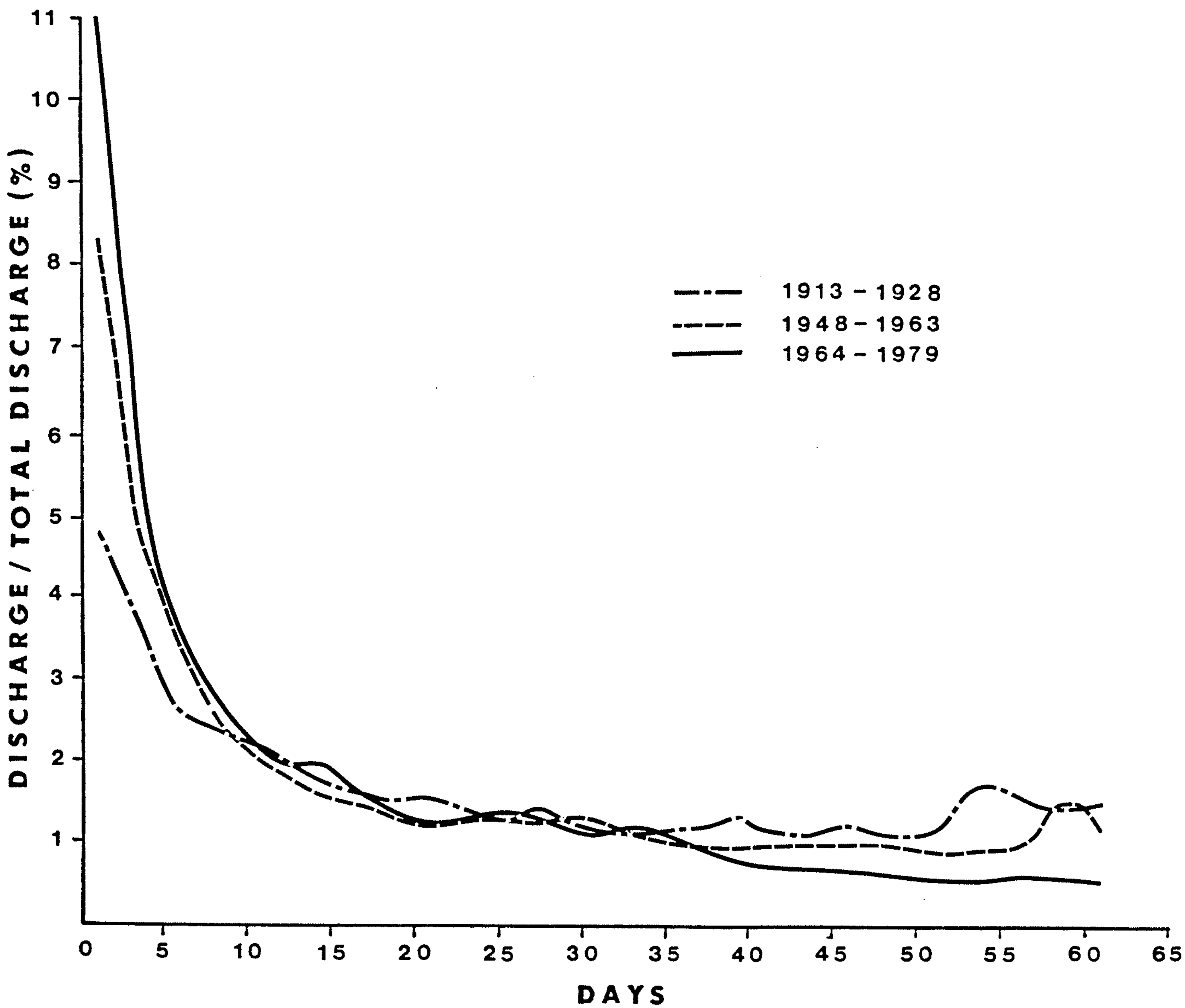


Figure 3.22 Spring post peak flows as a percentage of total discharge.

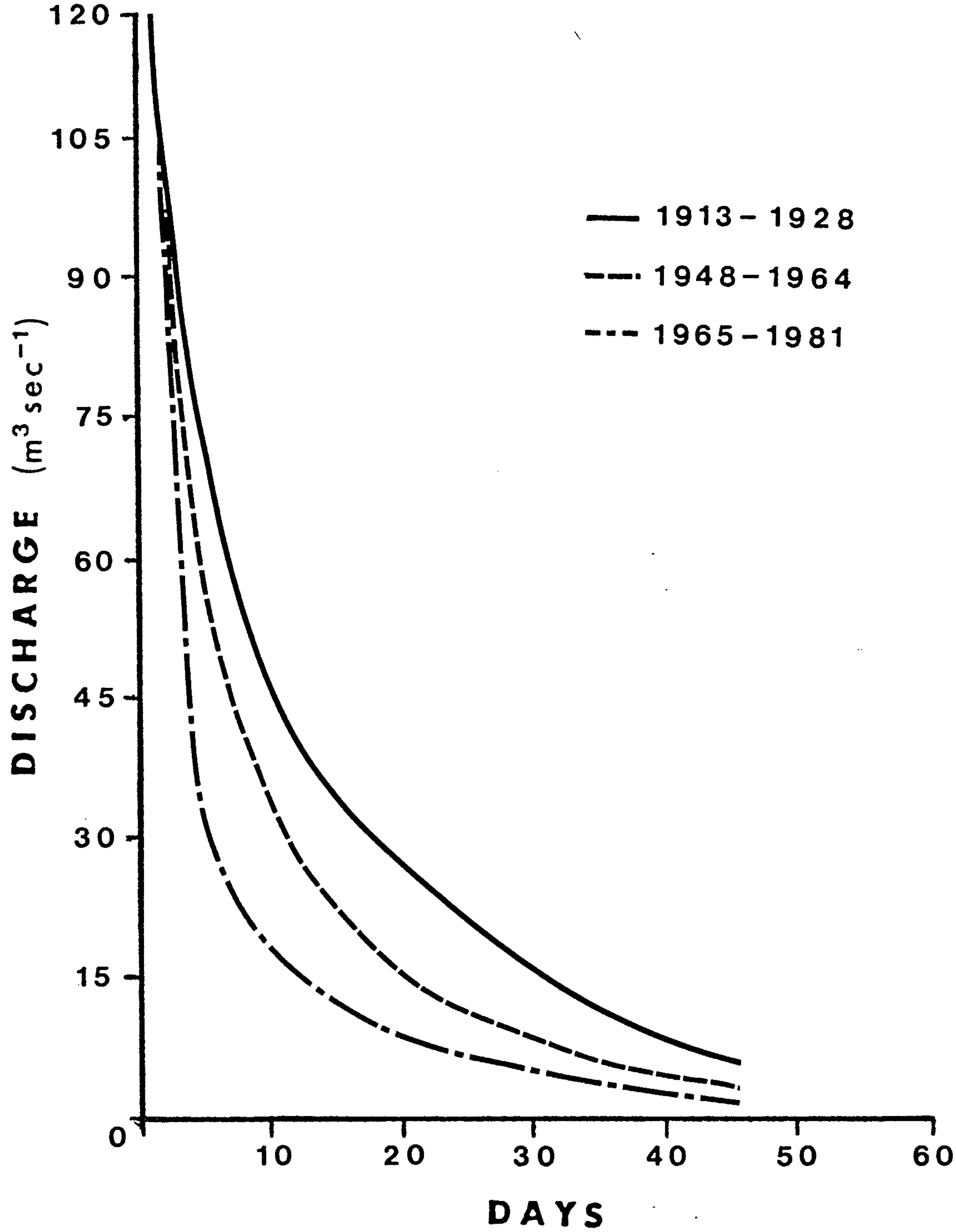


Figure 3.23 Spring runoff hydrographs adjusted to average annual peak discharge.

limb, indicating rapid attenuation in flow. The results strongly support the other analysis previously described, regarding change in the spring runoff hydrograph over time.

3.2.4 Recession Limb Analysis

The coefficient K in the recession limb equation of the hydrograph was determined for 8 years in the period 1913-28 and 9 years in the 1948-81 period. Several K's were computed for each spring runoff hydrograph (Table 3.7). The K values computed in the 5-10 day period after peak flow were used for comparison between time periods. The mean K for 1913-28 was 12.51 and for the 1948-81 period it was 8.68. The difference was significant at the 95% level of confidence. High K values indicate a shallow recession limb while low K values indicate rapid attenuation of the recession limb. The analysis indicates that spring flows attenuate more rapidly after peak flow in the latter time period than in the earlier one.

3.2.5 Discussion

The hydrograph analysis showed distinctly that the recession limb of the flood hydrograph, which is characteristic of the physiography of the watershed, changed over time. The recession limb attenuation became steeper and peak flows higher over the period 1948-81. Every test of the data indicated this response. The tests included normalizing, averaging, unitizing, and K factor analysis.

Table 3.7: Recession Limb Coefficient K

Year	Date	K
1914	May 14-19	11.56
1915	Apr 18-22	16.59
1917	May 15-22	9.69
1921	Apr 17-22	5.25
1924	May 3-31	16.91
1925	Apr 10-19	8.76
1926	Apr 27-May 3	9.71
1928	May 8-21	21.57
Mean 1914-28		12.51
1949	Apr 12-17	12.07
1952	Apr 11-17	8.95
1958	Apr 9-19	10.84
1962	Apr 20-May 1	4.10
1969	Apr 24-May 1	6.51
1971	Apr 24-29	10.97
1972	Apr 22-25	7.44
1979	May 1- 6	8.07
1981	Apr 3- 9	9.21
Mean 1948-81		8.68

Many authors have studied the effects vegetation have on storm hydrographs (Harrold 1971, Johnston 1984, Owe 1985, Swanson and Hillman 1977, and Sangvaree and Yevjevich 1977). In a Tennessee watershed (Harrold 1971) comparison of hydrographs before and after clear cutting showed that peak flow from spring runoff had increased by 3 times . The yield also increased by more than 3 times for a 1 in 2 year flood.

A Colorado study showed that unit hydrographs from small catchments were affected by land use (Sangvaree and Yevjevich 1977). It was discovered that agricultural land use caused greater peak flow rates and faster surface runoff than forested watersheds. A clear cut area in Alberta showed an increase in water yield, which was successfully predicted using a model (Swanson and Hillman 1977). The results also showed a 59% increase in spring snowmelt runoff, 27% increase in annual yield and an increase in peak flow rate of 50%.

The consensus from many studies is that forest clearing or removal increases water yield. The specifics of the increase in terms of peak flow timing or magnitude is variable in the literature. There appears to be no doubt that land use change has an effect on the timing, duration and magnitude of runoff. The main reason for this is the removal of vegetation.

Surface vegetation affects runoff in several ways. It intercepts and absorbs precipitation; it slows down and spreads out surface water allowing more time for infiltration; vegetation evacuates the root zone of water allowing more infiltration and reducing runoff. The removal of vegetation therefore increases both the speed and total volume of surface runoff.

The Valley River has undergone major changes in land use since 1913. The observed results of the various tests applied to runoff data are consistent with the current state of knowledge regarding the the effects of vegetative cover on the hydrologic regime. The significance of the results are related to the impact the altered flow regime has on instream biotic integrity, flooding, and erosion and sedimentation. These factors are beyond the scope of this study.

3.3 HYDROLOGIC MODELLING

Hydrologic modelling involves the use of mathematical equations to predict the response of a watershed under specified conditions. The models can be useful in predicting the hydrologic response to changing land use on a watershed. Since detailed land use change information was already computed for Valley River, its impact on storm hydrographs in the region was estimated.

Two hydrologic models were used to estimate how present and historic land use affected design storm hydrographs. The models used were SCS and HYMO (Soil Cons. Ser. 1972a, Williams and Hann 1973). The models were selected for their relative ease of use and their capacity to handle land use as a specific factor in determining runoff and peak flow. The SCS model was applied to land in the Silver Creek watershed only and the HYMO model was used on both Silver and Pleasant Valley Creeks (Figure 3.24). The SCS model required more manual calculation than the computerized HYMO model and was used on only one of the sub-watersheds. Both models allow the input of a soil/cover complex number as a measure of runoff potential for any specified land use. The models use different methods for determining the unit hydrograph and therefore the shape of the flood hydrograph differs between them, although the volume of runoff remains the same. The HYMO model had the additional ability to route flood flows through a watershed.

3.3.1 Silver Creek

Silver Creek watershed is characterized by moderate slopes (2-5%) and soils of hydrologic soil group B and C. The Grifton and Meharry soil associations comprise the bulk of the agricultural section of the watershed. The majority of the watershed is in native forest (77%).

Flood hydrographs were simulated for 9 HUs in Silver Creek and routed downstream to its junction with the Valley River (Figure 3.25). CN values were calculated for the years 1948, 1969, 1981 for HUs 8&9 only, and used in hydrograph computation (Table 3.8). The other HUs had no change in land use which necessitated the calculation of the CN value for one year only. A constant CN value was assumed for that part of the watershed inside Duck Mountain Provin-

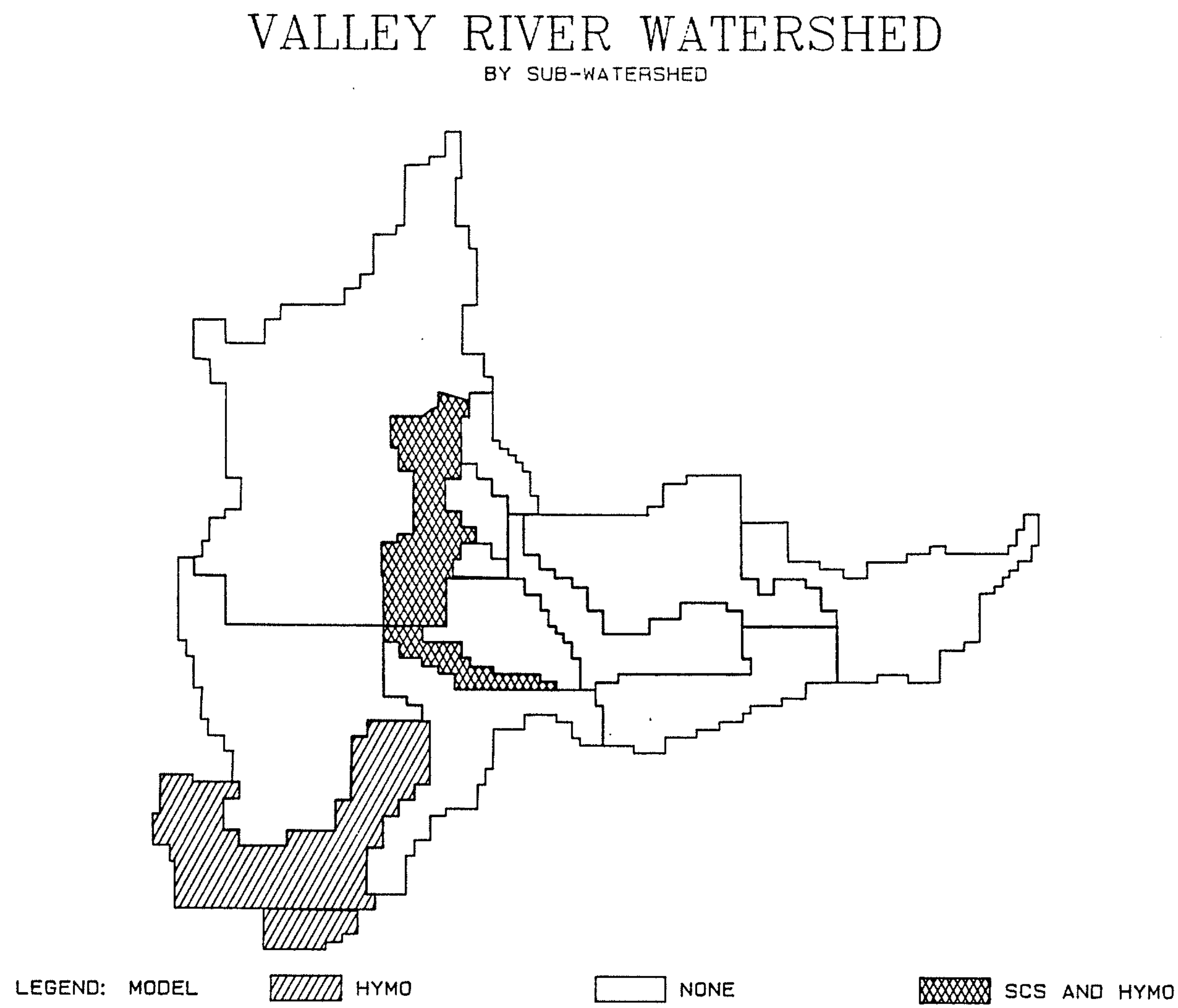


Figure 3.24 Location of hydrologic model application.

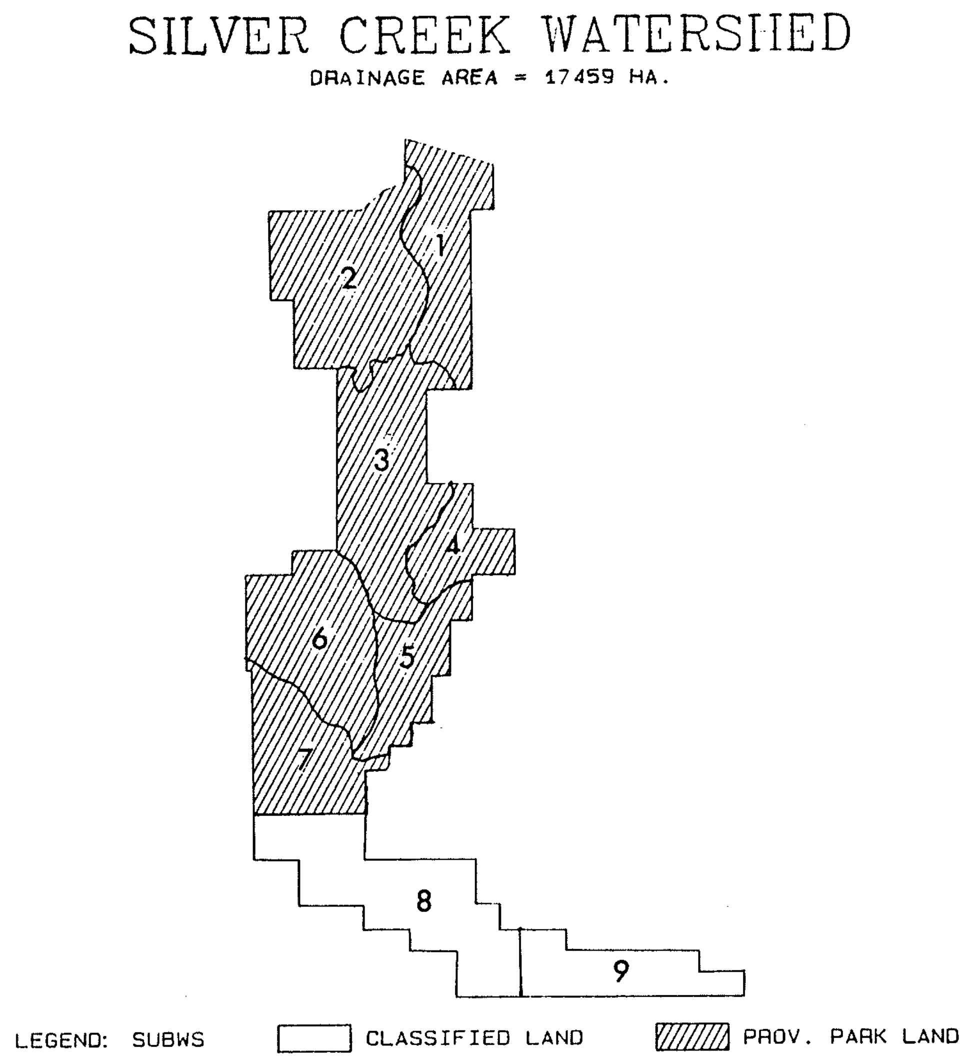


Figure 3.25 Silver Creek hydrologic units (HUs).

cial Forest and Park. Since there was no soil classification for the area, the hydrologic soil group was assumed to be B. The land use in the area was assumed to be 90% woodland, 5% wetland, and 5% lake.

Table 3.8: Silver Creek HU Parameters

HU	Flow Length (km)	Route Length (km)	Basin Slope (%)	Drainage Area(km^2)	Basin Height (m)	CN		
						1948	1969	1981
1	10.92	-	3.24	18.83	79.3	54.96	-	-
2	10.26	-	3.41	30.51	58.0	57.30	-	-
3	13.68	13.68	3.10	26.08	126.6	54.13	-	-
4	2.14	-	2.68	9.84	65.6	54.61	-	-
5	6.77	6.77	2.01	11.32	70.2	54.58	-	-
6	9.35	-	2.45	20.88	93.0	53.54	-	-
7	4.58	3.93	4.26	16.34	90.0	54.59	-	-
8	12.00	12.00	0.92	27.84	83.9	65.46	68.41	68.59
9	10.50	10.50	0.83	12.95	41.2	76.17	77.13	76.10

For a design 24 hour storm of 93.1 mm, the runoff increased 5.5% between 1948 and 1980 due to land use changes on 4079 hectares not inside Duck Mountain Park (Figure 3.26). The peak flow rate as determined by HYMO, increased from 33.4 m^3/sec to 36.1 m^3/sec or 7.9%. The 1969 peak flow rate was nearly identical to 1981 because the CN

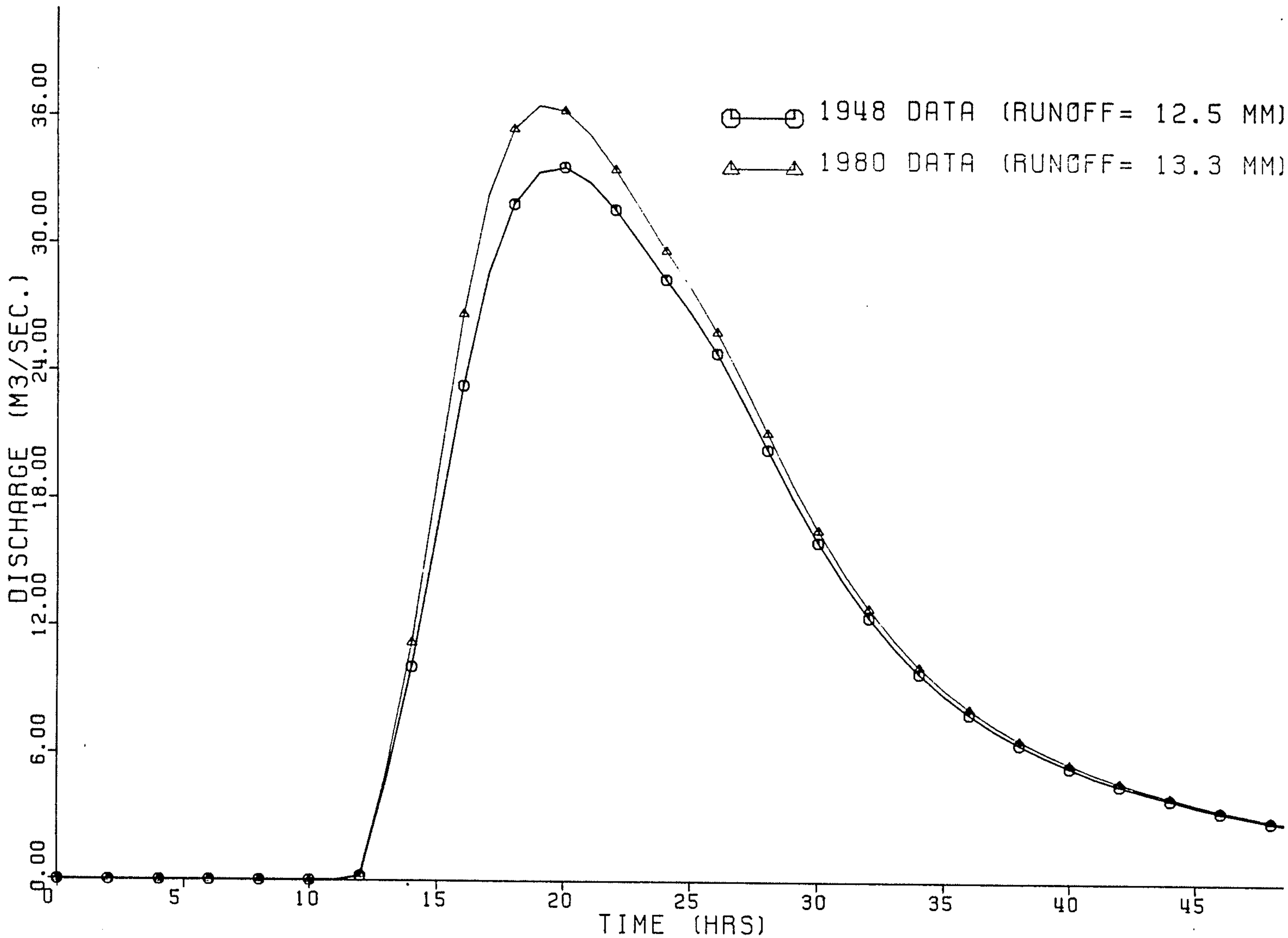


Figure 3.26 SCS storm hydrographs for 1948 and 1980 land use.

values changed very little between these years (Table 3.8). The time to peak did not change between 1969 and 1981. It remained constant at 19.5 hours. Tp may be more a function of rainfall distribution and intensity than land use (Hill et al. 1987).

A comparison was made of the computed hydrographs on HU 9 and HU 8. HU 8 had only 22.0 mm of runoff as compared to 37.9 mm in HU 9 for 1948 land use. The same relationship was true under 1981 land use patterns. The CN value for HU 8 was lower than HU 9 for both years which accounts for the lower volume of runoff. HU 8 however had a higher peak flow rate than HU 9, which was the result of steeper topography on HU 8. HU 8 also showed a greater change in peak flow rate and runoff volume than HU 9 between 1948 and 1969. This was the result of more intensive agri-development on HU 8 than on HU 9.

Runoff as a percent of rainfall was highest on the agricultural HUs (8&9) (Table 3.9). The percent runoff on unaltered HUs was between 9 and 13%, while the developed HUs had between 23 and 40% runoff. HU 9 had the highest percent runoff at approx. 40%. HU 8 only had a maximum of 28.1% runoff. HU 9 had a greater area of land under cultivation than HU 8 which caused the difference in percent runoff between HU 8 & 9.

Table 3.9: Silver Creek HYMO Results*

HU	Year	Peak Flow (cms)	Runoff (mm)	Runoff (%)
1	1981	4.49	10.2	11.0
2	1981	8.03	12.5	13.4
3	1981	5.96	9.5	10.2
4	1981	3.33	9.9	10.6
5	1981	3.34	9.9	10.6
6	1981	4.93	8.9	9.6
7	1981	6.00	9.9	10.6
8	1948	15.59	22.0	23.6
	1969	18.99	26.0	27.9
	1981	19.21	26.2	28.1
9	1948	10.92	37.9	40.7
	1969	11.46	39.6	42.5
	1981	10.88	37.8	40.6
TOT	1948	33.45	12.6	13.5
	1969	36.32	13.3	14.3
	1981	36.10	13.3	14.2

* For a design rainstorm of 24 hour duration, Type II rainfall distribution, and a return period of 10 years.

3.3.2 Pleasant Valley Creek

Flood hydrographs were simulated on 8 HUs in the watershed and routed downstream to the junction with the Valley River. The watershed gross drainage area was much greater than the actual contributing drainage area (Figure

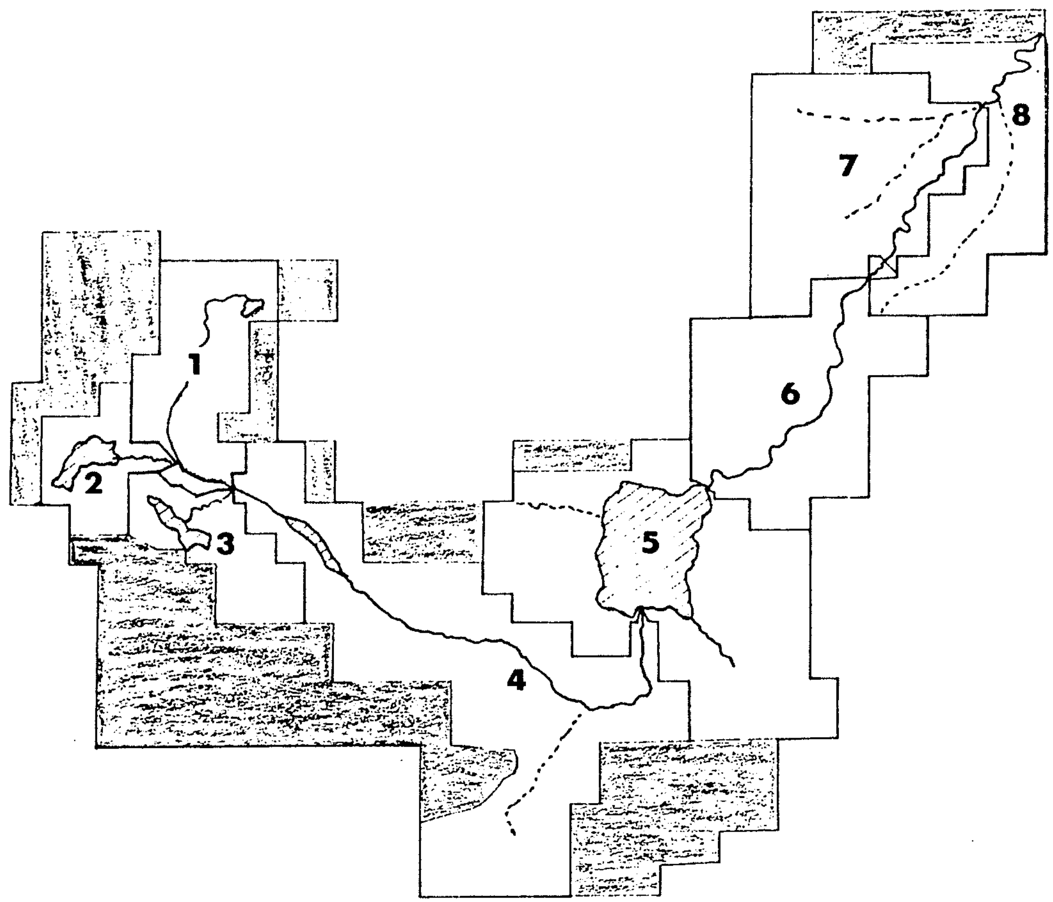
3.27). The upper half of the watershed is characterized by low slopes and wetlands and is sparsely developed for agriculture. The soils belong to hydrologic soil group B and the principal soil group is the Waitville Association (Ehrlich et al. 1959).

The lower half of the watershed has good drainage and moderate slopes and is better suited to agricultural development. The soils belong to hydrologic soil group C of the Meharry Association. There are some clay and clay loam soils also that have high runoff potential and are classed as soil group D.

Approximately mid way in the watershed there is a large area of wetland and peat soil. The area was developed into a storage reservoir in 1972 and can store up to 15,425 dam^3 (12,500 ac.ft.)· Pleasant Valley Reservoir had a dramatic effect on the 1981 simulated hydrograph in terms of runoff and peak flow rate. The reservoir was incorporated into the HYMO model by using a reservoir routing procedure.

Storm runoff (using the SCS method) for the watershed increased by 11.1% between 1948 and 1969 (Figure 3.28). Runoff and peak flow probably did not increase significantly between 1969 and 1981 as a result of little change in the CN value for the two years (Table 3.10). The building of Pleasant Valley Reservoir influenced the 1981 hydrograph and masked any changes in shape between 1969 and 1981. Peak

PLEASANT VALLEY CREEK



DRAINAGE NON CONTRIBUTING CONTRIBUTING LAKE

Figure 3.27 Pleasant Valley Creek Hydrologic Units.

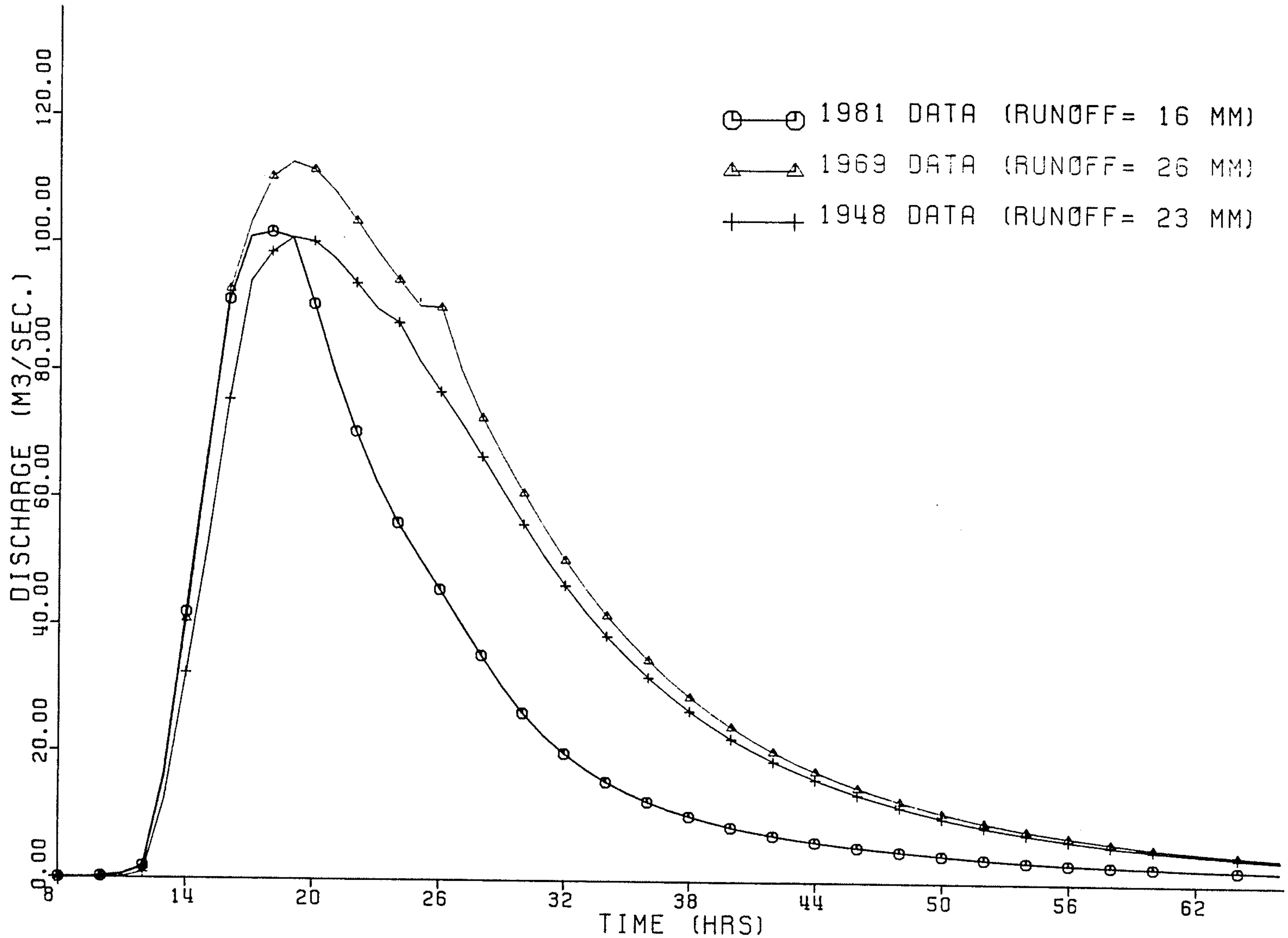


Figure 3.28 Simulated storm hydrographs for 1948, 1969, and 1981 land use on Pleasant Valley Creek.

Table 3.10: **Pleasant Valley Creek HU Parameters**

HU	Flow Length (km)	Route Length (km)	Basin Slope (%)	Drainage Area(km^2)	Basin Height (m)	CN		
						1948	1969	1981
1	9.53	1.77	2.55	16.12	33.6	65.98	68.5	-
2	4.96	-	0.68	8.43	25.9	73.07	73.7	-
3	7.92	-	0.90	10.20	27.5	68.27	68.3	-
4	20.35	20.35	1.68	51.96	54.3	57.52	59.0	-
5	13.63	3.88	2.34	45.65	100.0	68.18	69.38	-
6	12.49	11.56	1.55	28.81	91.5	72.49	77.21	-
7	10.66	6.82	2.09	30.76	114.4	70.12	76.5	77.0
8	12.38	4.94	1.00	21.41	99.1	79.33	82.73	83.2

flow rate increased by 11.2% from 100.1 m^3/sec to 112.7 m^3/sec between 1948 and 1981. Time to peak flow was constant at 19.0 hours, although the 1969 hydrograph had a steeper ascending limb.

The 1981 hydrograph reflects the effect of the construction of Pleasant Valley Reservoir. There was only 15.8 mm of runoff during the simulation periods and a peak flow rate of 101.9 m^3/sec from the design rainstorm. Because of the large surface area of the reservoir the runoff volume was spread out over a much greater period of time which gives the appearance in the 1981 hydrograph, of reduced runoff.

The 8 HUs show different responses to land use change between 1948 and 1981. A map describing percent change in peak flow and runoff volume across the basin was created to show the differences among HUs (Figure 3.29). HU 7 showed the greatest change in peak flow rate and runoff volume in response to agri-development (Table 3.11). The upper section of the watershed, HUs 2&3 showed little change due to wetland and peat restrictions on agricultural development. It was mainly at the lower end of the watershed, HUS 6-8, that underwent the greatest change. The 1981 figures were not used in the calculations since minimal change took place between 1969 and 1981.

3.3.3 Silver Creek vs. Pleasant Valley Creek

The magnitude of peak flow was much greater for Pleasant Valley Creek than Silver Creek even though the contributing drainage areas were similar (213 km^2 for Pleasant Valley Creek and 175 km^2 for Silver Creek). The percent runoff was much higher on Pleasant Valley at 27.6% as compared to 14.3% on Silver Creek in the same year . The peak flow rate for Silver Creek in 1969 was 36.3 m^3/sec, while on Pleasant Valley Creek for the same year it was 112.8 m^3/sec (Figure 3.30). This is illustrative of the large impact agricultural land use and development can have on runoff and peak flow, since 77% of Silver Creek is in native forest and relatively undeveloped.

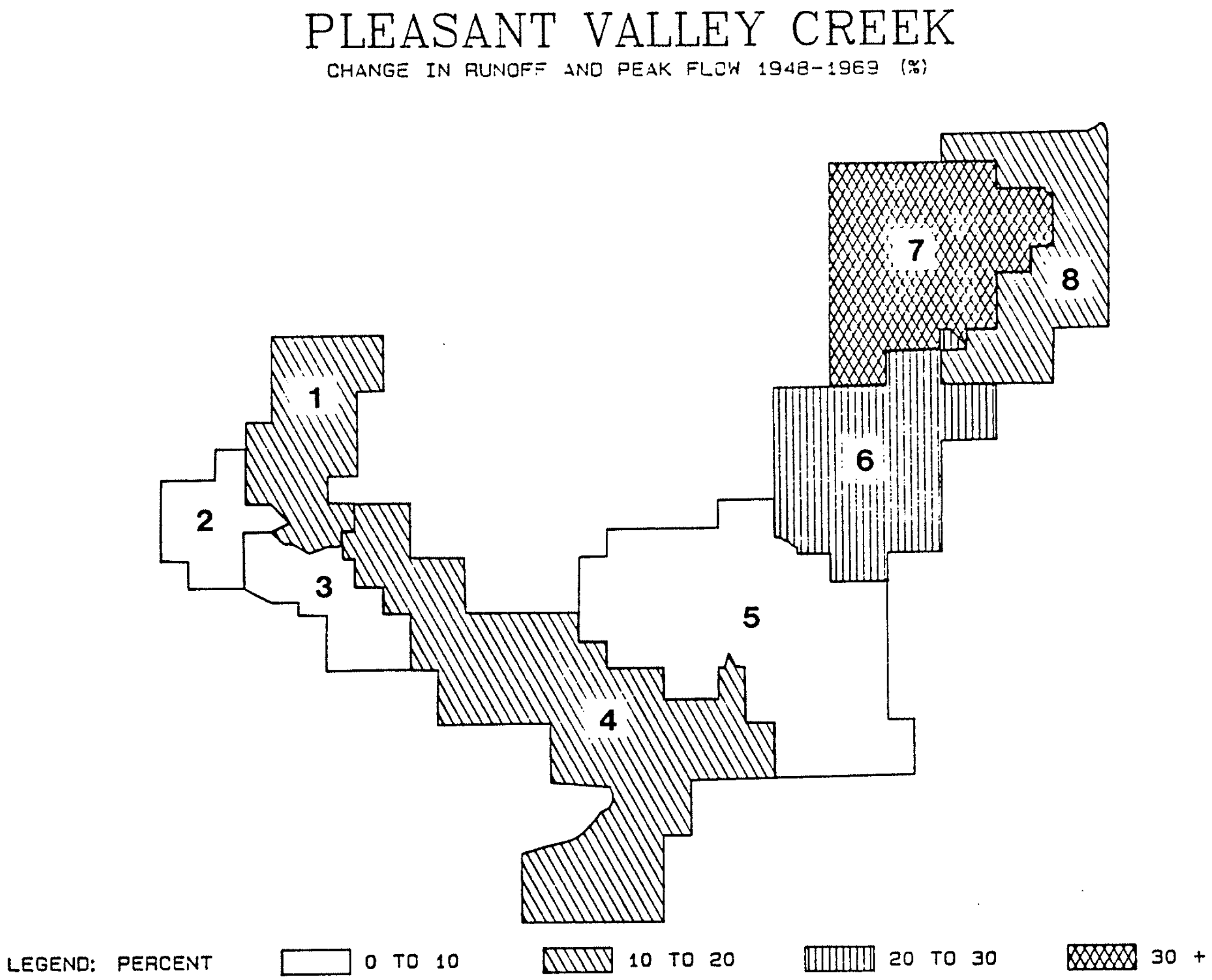


Figure 3.29 Percent change in runoff and peak flow from 1948-69 on Pleasant Valley Creek.

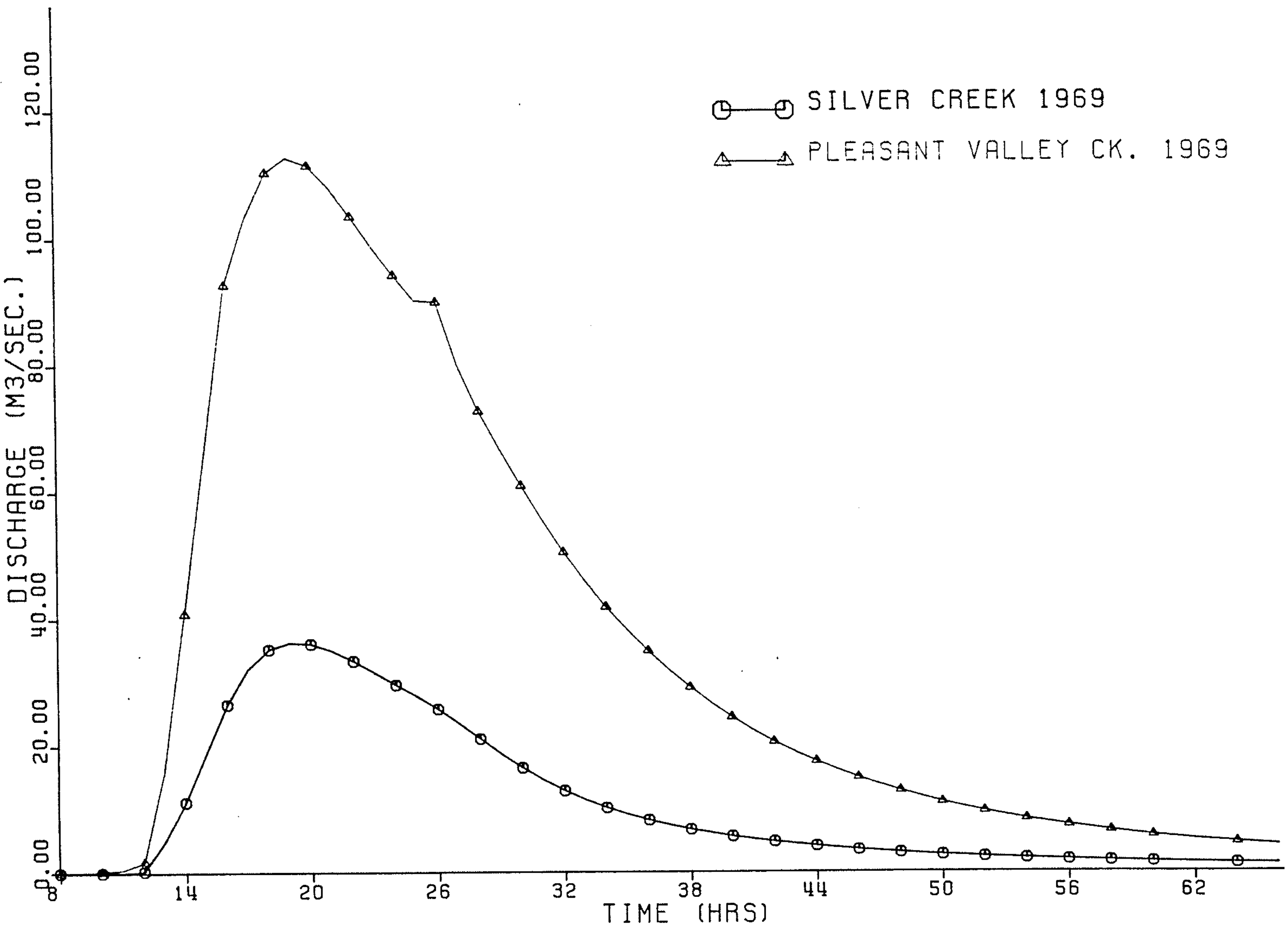


Figure 3.30 Comparison of storm hydrographs between Silver and Pleasant Valley Creeks for 1969 land use.

Table 3.11: Pleasant Valley Creek HYMO Results*

HU	Year	Peak Flow (cms)	Runoff (mm)	Runoff (%)
1	1948	7.04	22.6	24
	1969	8.28	26.0	28
2	1948	8.56	32.8	35
	1969	8.87	33.8	36
3	1948	5.53	25.6	27
	1969	5.53	25.6	27
4	1948	8.44	12.7	14
	1969	9.52	14.3	15
5	1948	29.37	25.7	28
	1969	31.65	27.4	29
6	1948	25.43	32.1	34
	1969	32.80	40.0	43
	1981	33.64	40.8	44
7	1948	29.97	28.4	31
	1969	43.17	38.7	41
	1981	44.28	39.5	42
8	1948	29.32	43.6	47
	1969	34.39	50.1	54
	1981	35.21	51.2	55
TOTAL	1948	100.9	23.2	25
	1969	112.9	25.7	28
	1981	102.0	15.9	17

* For a design rainstorm of 24 hour duration, Type II rainfall distribution, and a return period of 10 years.

Changes in land use caused only an 8% increase in peak flow rate, and a 5.5% increase in runoff on Silver Creek between 1948 and 1981, but caused an 11.8% increase in peak flow and an 11.1% increase in runoff on Pleasant Valley Creek between 1948 and 1981. Other studies have demonstrated the effect of land use or cover has on runoff and peak flow (Harrold 1971, Owe 1985). Owe (1985) found changes in water yield of over 50% over a period of 50 years on a stream. The change was directly attributable to alterations in the surface character of the basin. The loss of vegetation on a watershed due to clearing of native cover, changes the water infiltration rate at the soil surface. This usually results in more runoff, since there is less vegetation to evacuate the root zone prior to a rainfall event (Harrold 1971).

3.3.4 SCS vs. HYMO

Hydrographs computed for Silver Creek were done with both the SCS method and HYMO. The results show that even though the volume of runoff is the same the time to peak flow (Tp) and the peak flow rate differ (Table 3.12). The SCS method produced a longer Tp and a lower peak flow than HYMO under the same conditions. The time to peak parameter actually varied only slightly for all simulations and appears to be relatively unresponsive to changes in land

Table 3.12: HYMO vs. SCS on Silver Creek

HU	Year	HYMO			SCS		
		Peak (cms)	Runoff (mm)	Tp (hr)	Peak (cms)	Runoff (mm)	Tp (hr)
1	1948	4.49	10.2	16.0	3.96	10.2	20.2
2	1948	8.02	12.5	17.0	8.97	12.5	18.8
3	1948	5.95	9.5	16.0	4.54	9.5	23.5
4	1948	3.33	9.9	14.5	4.16	9.9	14.6
5	1948	3.34	9.9	15.0	2.54	9.9	20.0
6	1948	4.92	8.9	15.5	3.73	8.9	21.3
7	1948	6.00	9.9	14.0	4.47	9.9	17.0
8	1948	15.58	22.0	16.0	9.88	22.0	23.0
	1969	18.98	26.0	16.0	12.89	26.0	23.2
9	1948	10.91	37.9	16.0	10.88	37.9	19.1
	1969	11.46	39.6	16.0	11.73	39.6	20.0

use. A study in Louisianna (Hill et al. 1987) showed similar results with Tp. Tp is independent of land use change because it is a function of the spatial distribution of the rainfall, which is not accounted for in the model.

The methods use different measures of basin topography. HYMO uses total difference in watershed elevation (HT) divided by the flow length (L). The slope then equals HT/L . The SCS method uses an average basin slope in its computations. It is calculated by using a point intersection method on a topographic sheet. HYMO was the preferred model for basin comparisons, because of its ability to route and add hydrographs.

3.4 MULTIPLE REGRESSION ANALYSIS

Multiple regression analysis was performed on Valley River hydrometric and climatic data. The analysis was used to determine the best factors for predicting runoff and peak flow rate. The analysis was also used to predict changes in hydrologic response due to land use changes. The regression was performed on 34 years of data, from 1948 to 1981.

Multiple regression equations produced from the analysis are shown in Table 3.13 for runoff and in Table 3.14 for peak flow. The first runs of the regression were done in both linear and logarithm form. It became apparent that the log form using Fletcher Optimization[2] produced better results as indicated by Pearson's product moment correlation coefficient (r). The difference between the two forms was more pronounced for peak flow equations than runoff equations (Table 3.13, Eq.1-4).

3.4.1 Runoff Equations

It was found that the MI variable added little or nothing to the accuracy of runoff equations, and the

2. Fletcher optimization was available on Man. Water Resources statistical programs for hydrometric data.

Table 3.13: **Runoff Equations**

1. $RO = -1.405 + 0.29\ TP + 0.008\ API - 0.012\ MI$

   $r^2 = 0.67$ SE = 0.49 in.   n = 34 years

2. $RO = (7.878 \times 10^{-4})\ TP^{1.701}\ API^{0.876}\ MI^{0.052}$

   $r^2 = 0.69$ SE = 0.43 in.   n = 34 years

3. $RO = -1.467 + 0.292\ TP + 0.00819\ API$

   $r^2 = 0.69$ SE = 0.44 in.   n = 34 years

4. $RO = (8.04 \times 10^{-4})\ TP^{1.67}\ API^{0.902}$

   $r^2 = 0.71$ SE = 0.42 in.   n = 34 years

5. $RO = (6.194 \times 10^{-6})\ TP^{2.073}\ API^{1.806}$

   $r^2 = 0.72$ SE = 0.42 in.   n = 17 years (1948-64)

6. $RO = (9.27 \times 10^{-4})\ TP^{-1.562}\ API^{0.896}$

   $r^2 = 0.66$ SE = 0.46 in.   n = 17 years (1965-81)

7. $RO = (5.449 \times 10^{-4})\ TP^{1.984}\ API^{0.863}$

   $r^2 = 0.59$ SE = 0.52 in.   n = 17 years (1948-80 even)

8. $RO = (6.013 \times 10^{-4})\ TP^{1.504}\ API^{1.017}$

   $r^2 = 0.72$ SE = 0.39 in.   n =17 years (1949-81 odd)

9. $RO = -0.654 + 0.289\ TP + 0.00866\ API - 0.016\ TIL$

   $r^2 = 0.67$ SE = 0.43 in.   n = 34 years

10. $RO = 0.0456 \times TP^{1.734}\ API^{1.212}\ TIL^{-1.414}$

   $r^2 = 0.74$ SE = 0.40 in.   n = 34 years

Table 3.14: Peak Equations

1. $PK = -5.805 \times 10^{3} + 965.13\ TP + 27.597\ API + 61.485\ MI$

   $r^2 = 0.55$ SE = 1902 cfs n = 34 years

2. $PK = 3.951 \times 10^{-3}\ TP^{2.597}\ API^{1.81}\ MI^{0.126}$

   $r^2 = 0.77$ SE = 1347 cfs n = 34 years

3. $PK = 1.435 \times 10^{-3}\ TP^{2.297}\ API^{1.973}\ MI^{0.556}$

   $r^2 = 0.74$ SE = 916 cfs n = 17 years (1948-64)

4. $PK = 4.017 \times 10^{-2}\ TP^{2.68}\ API^{1.337}\ MI^{0.067}$

   $r^2 = 0.83$ SE = 1479 cfs n = 17 years (1965-81)

5. $PK = 1.333 \times 10^{-2}\ TP^{2.355}\ API^{1.541}\ MI^{0.368}$

   $r^2 = 0.74$ SE = 1213 cfs n = 17 years (1948-80 even)

6. $PK = 5.010 \times 10^{-4}\ TP^{3.149}\ API^{1.735}\ MI^{1.182}$

   $r^2 = 0.88$ SE = 1110 cfs n = 17 years (1949-81 odd)

7. $PK = -9999. + 982.2\ TP + 24.74\ API + 98.5\ MI + 77.7\ TIL$

   $r^2 = 0.55$ SE = 1894 cfs n = 34 years

8. $PK = 2.177 \times 10^{-4}\ TP^{2.510}\ API^{1.210}\ MI^{0.290}\ TIL^{1.420}$

   $r^2 = 0.77$ SE = 1319 cfs n = 34 years

variable was dropped from the regression (Table 3.13 Eq.1-4). The t-test on the regression coefficient for each independent variable in the equations also indicated the rejection of MI from the runoff equations.

The Durban-Watson test statistic d was produced for the linear regression equations to test for 1^{st} order auto-correlation between variables (Table 3.15). Auto-correlation often occurs when the relationship between two variables is directly influenced by time. First order auto-correlation never exceeded 0.243 for any of the equations tested. When TIL (Total Improved Land) was excluded auto-correlation was less than 0.10 with $d > 1.70$. The TIL variable is by definition in this study auto-correlated with time and it obviously influenced the test statistic d, although not to such a level as to reject the results.

Table 3.15: Durban-Watson 1^{st} Order Auto-correlation.

Model	d	Critical* Value	Result
RO = TP API TIL	1.283	1.13-1.36	inconclusive
PK = TP API MI	1.778	1.13-1.36	no autocorr.
PK = TP API MI TIL	1.784	1.13-1.36	no autocorr.

* For $\alpha = 0.01$

Plots of residuals versus time were done for the linear multiple regression equations in order to check visually for auto-correlation. None of the graphs indicated auto correlation as the plot points were widely scattered.

The data were split into two time periods 1948-64 and 1965-81 to see if there was any change in the hydrologic regime between the two periods (Table 3.13, Eqs.5&6). The 1965-81 equation actually predicted lower runoff volumes than the earlier period (Table 3.16). The peak equations (Table 3.14 Eqs.3&4) for the two periods showed that a higher peak flow rate was predicted on average for the more recent period (Table 3.17).

A statistical t-test was done on the predicted results from the runoff equations for the two time periods (Table 3.16). The t-test tests the null hypothesis (H_0) that the means of the predicted results from the two equations are not significantly different. The t-test results indicated that the means were not significantly different for runoff equations 5 and 6 (Table 3.13). The null hypothesis was accepted because t=1.1202 and the critical value for t to reject the null hypothesis at the 95% confidence level was 1.645 for n=66 degrees of freedom.

The results of the odd-even split data for runoff volume indicated there was a difference in the means of the predicted results, but it was not significant statistically (Eqs.7&8 Tables 3.13 & 3.16). T in the t-test was equal to 0.357 which means the null hypothesis was accepted. This indicates that any difference in predictions obtained by the

Table 3.16: Runoff Predictions (inches)

Year	Obs.	EQ.5 (1948 -64)	EQ.6 (1965 -81)	EQ.7 (Even)	EQ.8 (Odd)	EQ.4 (1948 -81)	EQ.10 (TIL)
1948	2.93	2.57	1.82	2.33	1.83	2.06	2.57
1949	0.33	0.56	0.61	0.60	0.63	0.64	0.74
1950	0.57	1.05	0.90	0.94	0.94	0.97	1.16
1951	0.70	0.87	0.79	0.79	0.82	0.84	0.98
1952	0.86	0.29	0.36	0.30	0.38	0.36	0.39
1953	0.77	0.51	0.60	0.60	0.60	0.63	0.66
1954	0.99	1.37	0.94	0.90	1.03	0.99	1.23
1955	1.36	0.48	0.47	0.40	0.51	0.48	0.54
1956	2.12	2.12	1.73	2.31	1.68	1.97	2.06
1957	1.99	2.20	1.66	2.11	1.66	1.87	2.01
1958	0.33	0.37	0.47	0.45	0.48	0.50	0.47
1959	0.29	0.26	0.37	0.34	0.38	0.38	0.35
1960	1.44	0.84	0.73	0.70	0.78	0.77	0.81
1961	0.03	0.08	0.18	0.15	0.18	0.18	0.14
1962	0.24	0.40	0.57	0.62	0.56	0.62	0.52
1963	0.22	0.65	0.69	0.70	0.70	0.73	0.68
1964	0.21	0.47	0.57	0.56	0.57	0.60	0.53
1965	0.30	0.28	0.40	0.37	0.40	0.41	0.35
1966	0.33	2.01	1.34	1.46	1.41	1.45	1.49
1967	1.54	1.91	1.59	2.07	1.56	1.80	1.62
1968	0.32	0.47	0.54	0.52	0.56	0.57	0.49
1969	0.64	0.31	0.45	0.44	0.45	0.47	0.37
1970	1.75	1.08	0.92	0.97	0.96	0.99	0.90
1971	1.13	0.79	0.66	0.60	0.72	0.69	0.64
1972	1.18	0.93	0.78	0.75	0.83	0.82	0.74
1973	0.06	0.10	0.20	0.16	0.20	0.20	0.14
1974	2.41	4.04	2.08	2.43	2.22	2.31	2.29
1975	1.19	0.94	0.89	0.97	0.91	0.97	0.79
1976	1.27	2.20	1.27	1.27	1.40	1.36	1.32
1977	0.11	0.10	0.22	0.19	0.22	0.22	0.14
1978	0.64	1.05	0.78	0.71	0.85	0.81	0.72
1979	2.55	4.65	2.57	3.41	2.64	2.94	2.61
1980	0.60	0.59	0.67	0.69	0.67	0.71	0.52
1981	0.14	1.04	0.85	0.84	0.90	0.90	0.74
MEAN		1.105	0.872	0.960	0.900	0.947	0.932
STD DEV		1.069	0.569	0.777	0.584	0.655	0.685
T-Test		$t = 1.12$		$t = 0.357$		$t = 0.090$	
		$\overline{Y}_{Eq5} = \overline{Y}_{Eq6}$		$\overline{Y}_{Eq7} = \overline{Y}_{Eq8}$		$\overline{Y}_{Eq4} = \overline{Y}_{Eq10}$	

Table 3.17: **Peak Flow Predictions(cfs)**

Year	Obs.	EQ.3 (1948 -64)	EQ.4 (1965 -81)	EQ.5 (Even)	EQ.6 (Odd)	EQ.2 (1948 -81)	EQ.8 (TIL)
1948	7945	7291	7981	6206	21849	6940	6297
1949	875	1183	1238	1671	1835	1055	1062
1950	2270	2780	2381	2225	5643	2220	2113
1951	1998	1666	1815	1474	2212	1649	1465
1952	1670	436	474	406	352	417	405
1953	1691	503	1104	615	357	825	751
1954	2341	3351	2332	2357	4805	2586	2692
1955	2450	976	743	762	1044	753	712
1956	2659	3601	7160	3972	6924	5332	5286
1957	2964	2757	6284	3152	3330	4896	4170
1958	847	809	832	752	1329	674	872
1959	409	648	567	575	1119	466	654
1960	2349	1550	1547	1312	1758	1491	1416
1961	64	81	160	108	54	103	154
1962	1211	1232	1261	1169	3796	915	1554
1963	302	1363	1513	1255	2212	1271	1556
1964	589	929	1106	901	1409	886	1165
1965	1288	550	617	538	781	484	701
1966	2359	5168	4408	3926	10042	4453	4529
1967	5049	2867	6139	3258	4599	4543	5063
1968	572	594	960	642	507	768	899
1969	3029	580	771	610	879	567	892
1970	3884	1614	2299	1569	1739	2015	2146
1971	4590	2350	1364	1604	4144	1463	1782
1972	2118	862	1583	930	483	1429	1292
1973	87	102	186	129	64	127	205
1974	9252	11159	9034	7902	24087	9832	9739
1975	2751	1541	2278	1554	2648	1863	2371
1976	3220	5870	3874	3894	9506	4473	4517
1977	174	103	219	139	67	142	245
1978	992	973	1517	946	442	1516	1305
1979	13596	8138	12923	7607	13601	11702	11977
1980	1387	1018	1430	1040	1405	1124	1699
1981	254	1502	1933	1387	1359	1813	2044
MEAN		2240	2646	1941	3994	2376	2445
STD DEV		2535	2953	2002	5757	2727	2671
T-TEST			$t = -0.608$		$t = -1.964$		$t = -0.105$
			$\overline{Y}_{Eq3} = \overline{Y}_{Eq4}$		$\overline{Y}_{Eq5} \neq \overline{Y}_{Eq6}$		$\overline{Y}_{Eq2} = \overline{Y}_{Eq8}$

time period equations for runoff (Eqs.5&6 Table 3.13) were not the result of random effects of data selection.

3.4.2 Peak Flow Equations

The same types of analysis were performed using peak flow rate as the dependent variable. Similar results to the runoff equations were obtained. The logarithmic transformation of the regression equations produced better results than linear (Eqs. 1&2 Table 3.14). The MI independent variable was left in all the analyses as it was found to be a significant contributing factor to peak flow rate prediction.

When the data were split into two time periods the regression equations for peak flow showed that the 1965-81 time period on average produced higher peak flows (Table 3.17). However, it was not statistically significant at the 95% confidence level (t=-0.6082).

Odd-even analysis showed there was a significant difference between the predictions of the odd and even equations (Eqs.5&6 Table 3.14 & 3.17). The H_0 was rejected at the 95% confidence level with t=1.9637 . This suggests there were some random effects associated with the input data that were causing the difference in peak flow prediction.

3.4.3 TIL Equations

TIL was added as an independent variable in the multiple regression analysis to assess its importance to peak flow and runoff prediction in spring. The runoff and peak flow equations for 34 years of data with TIL added are shown in Table 3.13 & 3.14. The TIL variable did not add any accuracy to the runoff volume prediction equations but worked well with the peak equations (Table 3.13). The TIL variable actually showed an inverse relationship to runoff volume for both linear and log equations.

The predicted means of runoff Equations 4 and 9 (Table 3.13) were tested for significance. The TIL variable was included in Equation 9. No significant difference existed between the predicted results of the equations (t=0.0904) (Table 3.16). The same result was obtained for peak equations where t=-0.1054 (Table 3.17). However the results do not entirely eliminate TIL as a contributor to peak flow magnitude. The TIL variable was found to be significant in all log forms of the prediction equations as evidenced by the t values, which expresses the probability of t obtaining a value t_a when r=0 for the partial regression coefficient.

To further test the influence of the TIL variable, TIL was held constant at 1948 levels in Equation 8 (Table 3.14). The mean of predicted peak flows was 53.9 m^3/sec whereas when TIL was allowed to vary the average peak flow rate was 69.3 m^3/sec. Although this does not represent a statistically significant difference it is indicative of the effect of the TIL variable.

Another test was performed on Equation 8 (Table 3.14). TP, API, and MI were held constant at their means and then TIL was allowed to vary for the 34 years of data. The result was a predicted peak flow of 41.1 m^3/sec for 1948 TIL and 64.1 m^3/sec for 1981 TIL. This represents a 56% increase in peak flow rate attributable to TIL change within the model from 1948 - 1981.

Multiple regression analysis (MRA) using climatic and land use variables to predict runoff volume was successfully used in Chester Creek basin (Owe 1985). Land use/cover was responsible for up to a 57% increase in runoff over 51 years of records. A study on two rivers in southern Manitoba showed TIL to be significant in predicting runoff and peak flow (Warkentin pers. comm.) The Rat and Boyne Rivers both showed increases in peak flow and runoff as a result of land use over a 60 year period.

The MRA technique has proven valuable in assessing the degree to which land use has impacted runoff and peak flow. The results are not entirely conclusive for Valley River but they are indicative of the effect land use can have on the hydrologic regime. TIL was not a strong independent variable mainly because it was based on 3 years data and extrapolated to 34 years using linear interpolation. More historical land use data are necessary before the TIL variable can accurately predict runoff and peak flow rate.

A longer period of record is also necessary to show the hydrologic effects of land use on a basin the size of Valley River. The regression analysis seems to indicate that in the period 1948 - 1981 land use change potentially caused between 28 and 56% increase in peak flow rate, depending on the technique used. The effect of land use on runoff volume was inconclusive.

3.5 SOIL EROSION AND SEDIMENTATION

Manitoba has 5.2 million hectares of land which is suitable for sustained annual production of cultivated crops. About 730,000 hectares has already been damaged by water and an equal area by wind (McKay 1984). Much of the land degradation has been masked by fertilizer and chemicals. Today, 30% of crop yield is due to the use of fertilizer. Therefore, soil loss is a serious threat to agricultural productivity in Manitoba and warrants immediate attention.

Soil erosion by water can be a destructive and wasteful process in agricultural areas. Soil particles are detached and transported by rainfall and snowmelt in a continuous process that can exceed the ability of the land to regenerate soil. The soil resource can therefore be exhausted by soil erosion due to surface and subsurface runoff.

Sediment, especially fine particles, in runoff from agricultural watersheds is considered a major non-point source pollutant and a carrier of soil adsorbed nutrients such as phosphorous and nitrogen (Foster 1983). Sediment delivered to watercourses from fields, pollutes by muddying the water, inhibiting photosynthesis, clogging fish gills and increasing biological oxygen demand (BOD), (Hartman et al. 1977). Sediment also reduces conveyance of channels and reservoirs due to sediment deposition (Foster and Meyer 1977). Sediment and sedimentation can destroy aquatic habitat, interfere with fish reproduction habitat and reduce species diversity. Deposition of suspended sediment instream has deprived walleye spawn of oxygen and reduced survival in the Valley River (Gaboury 1985). Excessive sediment loads have been known to discourage walleye from making spawning runs into streams (MDNR files).

Agri-development usually involves the clearing and draining of land which alters the hydrologic regime of the area. Soil loss usually increases with the development. The management of the land can also contribute to increased soil loss and sediment delivery.

The study of soil erosion in the Valley River watershed is concerned with the non point source pollution associated with agriculture. Soil erosion control can be practiced by the farmer to maintain productivity and protect the resource base. The control of non-point source pollution in agri-areas is accomplished by the same means, but for a different purpose. Control of soil loss on a watershed scale is not merely for the benefit of the individual but for the good of the environment and community as a whole. The effects of agri-development and land management were investigated in two sub-watersheds of the Valley River.

3.5.1 Soil Loss Results

3.5.1.1 Hydrologic Units

To isolate potential problem areas in the watershed, annual soil loss from cultivated fields was determined for all the hydrologic units (HUs) in Pleasant Valley Creek and HUs 1 and 2 in Silver Creek (Figures 3.25 & 3.27). Land use figures from 1948 only were used to illustrate soil loss at the HU scale, because detailed land use information was not available at a suitable scale for 1969 and 1980.

Pleasant Valley Creek, HU 6 had the greatest annual soil loss at 5142 tonnes. HU 6 also had the highest acreage of Sf (Table 3.18). The largest average loss per hectare was in HU 4 at 7.61 t/ha/yr. HU 4 was also the least developed HU at 8.3% Ag plus Sf. Summerfallow occupied 40.7% of the cultivated area in HU 4.

TABLE 3.18 Average Annual Soil Loss Attributable to Cultivation
(based on 1948 land use data)

HU	RKLS*	Land Use	Area (ha.)	% of HU area	C Factor	Soil Loss (tonnes)	Ag & Sf** Soil Loss (tonnes)	Ag & Sf** Soil Loss (t/ha.)
Pleasant Valley Creek								
1	6.424	Sf	76.1	4.7	.68	745		
		Ag	155.9	9.7	.31	696	1441	6.21
2	2.822	Sf	66.8	8.0	.68	288		
		Ag	144.5	17.0	.31	283	571	2.70
3	3.984	Sf	68.8	6.8	.68	419		
		Ag	195.5	19.0	.31	542	961	3.64
4	7.368	Sf	175.3	3.4	.68	1969		
		Ag	255.1	4.9	.31	1307	3276	7.61
5	4.742	Sf	344.5	7.6	.68	2492		
		Ag	542.1	11.9	.31	1787	4279	4.83
6	4.565	Sf	432.8	15.0	.68	3013		
		Ag	645.7	22.4	.31	2129	5142	4.77
7	4.846	Sf	294.7	9.6	.68	2178		
		Ag	541.7	17.7	.31	1825	4003	4.79
8	3.718	Sf	431.2	20.1	.68	2445		
		Ag	887.4	41.4	.31	2294	4739	3.59
Silver Creek								
9	2.180	Sf	324.3	25.0	.68	1078		
		Ag	583.4	45.0	.31	8841	962	2.16
8	2.871	Sf	411.3	14.8	.68	1801		
		Ag	664.4	23.8	.31	1327	3128	2.91

* R,K,LS = USLE factors
** Sf = summerfallow; Ag = agriculture

The large sources of sediment from Pleasant Valley to the Valley River are HUs 6, 7 and 8. They are all on the downstream side of Pleasant Valley reservoir near the Valley River. Agri-development is limited for HUs 1 through 5 due to steep topography and extensive wetlands. Pleasant Valley Reservoir acts as a sediment trap for any sediment from HUs 1 through 5. Consequently, they contribute very little sediment to Valley River. Land management to reduce soil erosion should concentrate on HUs 6 - 8 in Pleasant Valley Creek.

Silver Creek HU 8 showed greater soil loss than HU 9 at 2.91 t/ha/yr. HU 8 was only 38.6% developed for cultivation, while HU 9 was 70% developed. HU 8 had a larger proportion of cultivated land in Sf than HU 9. Considering HU 8 is more than twice the size of HU 9 and only partially developed for agriculture, it is more likely to be a greater source of sediment than HU 9.

On average Silver Creek HUs lost less soil per hectare than Pleasant Valley Creek HUs. The difference is in large part due to topographic factors and the extent of agri-land use as expressed by USLE factors (RKLS) (Table 3.18).

3.5.1.2 Sub-Watersheds

Total annual soil loss for the two watersheds is shown in Table 3.19. Pleasant Valley Creek lost between

3 and 4 times as much soil as Silver Creek in 1948, 1969 and 1980, although the contributing drainage area of Pleasant Valley Creek is only 22% larger. The main reason for the large difference is that 76.6% of Silver Creek watershed is inside Duck Mountain Provincial Park and Forest and unavailable for agri-development. Pleasant Valley has slightly steeper topography than Silver Creek and also has a greater area developed for agriculture.

Summerfallow and small grain production areas accounted for up to 82% of the soil loss on Silver Creek. The impact of land clearing and cultivation is evident from these figures, since 4/5 of the soil loss was the result of agri-development on 23.4% of the watershed.

Table 3.19 Total Annual Soil Loss

Year	Summerfallow		Small Grain		RG & Past		Woodland		Total	
	(ha)	(t)	(ha)	(t)	(ha)	(t)	(ha)	(t)	(t)	(t/ha/yr)
Pleasant Valley Creek										
1948	2440	19654	4854	17826	6370	754	13730	3091	41326	1.51
1969	3756	30262	7781	28557	6423	761	10142	2283	61883	2.20
1980	472	3803	11300	41501	6088	721	10941	2462	48488	1.68
Silver Creek										
1948	743	5879	1293	4662	833	97	13084	2892	13530	1.18
1969	838	6631	1732	6246	919	107	12526	2768	17752	0.90
1980	284	2247	2587	9325	570	66	12669	2800	14412	1.12

The summerfallow (Sf) and agriculture (Ag) land use categories accounted for 90 - 95% of the soil loss on Pleasant Valley Creek in the given years. Sf and Ag increased from 24% to 38.7% of the watershed area from 1948 - 1980. Therefore, in 1948, 24% of the area produced 90.7% and in 1980 38.7% produced 95% of the soil loss. Agri-development obviously has a large impact on soil loss.

The year of greatest soil loss was 1969 for both watersheds. It was the result of widespread use of summer-fallow. In 1948 and 1969, Sf accounted for almost half the soil loss on both watersheds. By 1980 only 16% of soil loss was due to Sf on Silver Creek and 7.8% on Pleasant Valley. The destructiveness of this type of land management is illustrated by these figures.

Sf and Ag were responsible for a 16.4% increase in soil loss between 1948 and 1969 on Silver Creek and 49.7% on Pleasant Valley Creek. Both watersheds had a decline in soil loss of 8.3% for Silver Creek and 21.6% for Pleasant Valley Creek, between 1969 and 1980, due mainly to the decline in summerfallow area.

3.5.2 Sediment Yield Results

Sediment yield was calculated based on a formula developed by Williams (1975), for HUs in Pleasant Valley and

Silver Creek. The storm hydrographs created in Section 3.3 were used as the hydrologic parameters for input into the equation. Therefore, the results are for a design storm event only, and not on an average annual basis as in the previous section. The USLE factors K, LS, C and P were used for soil loss parameters.

The sediment yield was altered by using different C factors for two types of land management. The C factors used were representative of good and poor land management. Poor land management corresponded to a mold board plow rotation with no meadow and no crop residue from the previous year's crop (Table 2.13). For good land management the C factor corresponded to a field with 1.12 - 1.68 tonnes/ha. of crop residue left on the field. Both cases were for crop period 2 (Table 2.13). The C factors were then weighted by the percentage of summerfallow and agriculture land use categories in the watershed. This produced sediment yields that were attributable to Ag and Sf.

3.5.2.1 Hydrologic Units

Sediment yield was calculated for HUs 6 through 8 on PLeasant Valley Creek, and HUs 8 and 9 on Silver Creek (Table 3.20). Pleasant Valley Creek HU 7 had the largest gross sediment yield (6988 t), although it was not the largest HU. It also had the largest increase in sediment yield between 1948 and 1980. HU 8 in Silver Creek produced more total sediment than HU 9 even though it was less developed for agriculture. KLS was higher in HU 8 than HU 9 and was a contributing factor. All HUs in Pleasant Valley had higher sediment yields (in t/ha) than Silver Creek, with the exception of HU 7 in 1948 only.

Table 3.20 **Sediment Yield**

Stream	HU	Year	Ag+Sf* (% of HU)	C Factors C_1	C Factors C_2	Sediment Yield C_1 (t)	Sediment Yield C_1 (t/ha)	Sediment Yield C_2 (t)	Sediment Yield C_2 (t/ha)
Silver	8	1948	40.0	0.180	0.068	1015	0.36	384	0.13
		1969	54.3	0.244	0.092	1691	0.61	639	0.22
		1980	57.3	0.258	0.097	1806	0.65	683	0.25
	9	1948	66.0	0.297	0.112	925	0.72	350	0.27
		1969	73.5	0.331	0.125	1085	0.83	410	0.31
		1980	81.9	0.369	0.139	1142	0.87	433	0.34
Pleasant Valley	6	1948	34.3	0.154	0.058	2292	0.79	868	0.29
		1969	58.7	0.264	0.100	5133	1.77	1940	0.67
		1980	60.5	0.272	0.103	5419	1.88	2049	0.72
	7	1948	27.4	0.123	0.047	2077	0.67	784	0.25
		1969	59.4	0.267	0.101	6560	2.13	2478	0.81
		1980	61.6	0.277	0.105	6988	2.27	2640	0.85
	8	1948	61.6	0.277	0.105	3681	1.73	1391	0.65
		1969	80.6	0.363	0.137	5693	2.65	2151	1.01
		1980	81.8	0.368	0.063	5917	2.76	2235	1.03

* Ag and Sf = agriculture and summerfallow land use categories.

3.5.2.2. Sub-watersheds

The largest sediment yield occurred in 1969 which corresponds to the year of largest percentage Sf on Pleasant Valley Creek (Table 3.21). The C factors used were weighted to reflect the areal extent of cultivated land (Ag and Sf) in the watershed for the given years. The CN values used in the storm hydrographs also reflect the cultivated area. The total sediment yield increased between 1948 and 1969 and decreased between 1969 and 1980 on Pleasant Valley. The 1948 - 1969 increase was 78.5% for Pleasant Valley and 36.5% for Silver Creek. Sediment yield decreased on Pleasant Valley by 26.4% between 1969-80 due to the impact of the Pleasant Valley reservoir on the storm hydrograph, while Silver Creek increased by 11.1% between 1969 and 1980. Pleasant Valley showed greater extremes in sediment yield because more of it was under cultivation.

Table 3.21 Sediment Yield from Cultivated Land (by Sub-watershed)

Stream	Year	Ag+Sf* (% of WS)	C Factors		Sediment Yield		
			C_1	C_2	C_1 (tonnes)	C_2 (tonnes)	C_1 (t/ha)
Silver	1948	9.57	0.043	0.016	1589	600	0.09
	1969	12.08	0.054	0.021	2170	820	0.12
	1980	13.50	0.061	0.023	2410	910	0.14
Pleasant	1948	23.97	0.108	0.041	10307	3894	0.48
	1969	37.91	0.171	0.064	18403	6952	0.86
	1980	38.68	0.174	0.066	13537	4750	0.63

* Ag and Sf = agriculture and summerfallow land use categories; WS = watershed.

The sediment yield from Pleasant Valley Creek was much higher than found in Silver Creek (Table 3.21). Pleasant Valley Creek produced up to 8.5 times as much sediment (by volume) as Silver Creek in 1948, 1969 and 1980. This is a direct result of the storm hydrographs used in determining sediment yield. The runoff volume was almost double and the peak flow rate triple that of Silver Creek (Section 3.3). The amount of sediment produced by Pleasant Valley was greatly reduced in 1980 by the building of the Pleasant Valley Reservoir in 1972.

The impact of summerfallow, residue management, extent of agri-development, and topographic factors were all incorporated into the model. The CN values used in synthesizing the storm hydrographs reflect the land treatment and hydrologic properties of the soil. Tables 3.8 & 3.10 illustrate the different CN values for the three years. Part of the reason for the higher CN values in HUs 8 - 10 in Pleasant Valley was more land was developed for agriculture than in Silver Creek HUs. Higher CN values under the same conditions results in greater runoff and higher peak flow rate. The total relief and drainage area caused differences in water and sediment yield as well (Tables 3.8 & 3.10).

The large volume of sediment generated by the design rainstorm is indicative of the impact a single storm can have on annual erosion losses (Foster and Meyers 1977). The 113 m^3/s peak flow rate obtained for Pleasant Valley in the 1969 storm hydrograph represents a 1 in 5 year peak flow on the entire Valley River. The similarity in amount of sediment produced by Pleasant Valley in the design rainstorm, when compared to Valley River annual sediment yield was a result of the large flow simulated.

3.5.3 Multiple Regression Analysis

Penner and Oshway (1983) determined the annual sediment yield of the Valley River watershed from 1950 - 1980. The sediment yields for the early years were determined from a sediment-discharge curve calculated from only two years data. The R factor of the USLE was calculated for 17 years from 1960 - 1976 (Steele 1979). R was linearly regressed against the sediment yield from the common years to test the strength of the relationship between the two factors. R was used because KLS was constant for all years and C was impossible to determine for the whole 2800 km^2 watershed.

Other factors were also used in the regression analysis. The dependent and independent variables and the results are shown in Table 3.22

The sediment yield from the spring snowmelt event (Sed-S) was significantly correlated with Rs ($r=0.54$) at the 95% confidence level. The Rs variable explains approximately 30% of the variation observed. The Sf variable was added to the regression and r increased to 0.60 although the Sf variable was not significant. Only Rs was a significant factor in predicting sediment yield in spring.

Annual R (USLE rainfall factor) did not significantly correlate with annual sediment yield (Sed-A = Rt). This may indicate upland areas as a source of sediment. Suspended sediment load from upland areas is influenced more by the location of a storm and its intensity, rather than having a direct relationship to discharge.

There were many sources of error in the synthesis of the variables. The Rt variable was calculated for only one station and on a very large watershed. Since rainstorms can be very localized events, the R factor is not truly representative of the real watershed R. The sediment variables were produced from a curve based on two years data. The Sf figures were representative of an area much larger (Census District 6) than the Valley River watershed. This probably reduced the strength of the relationship between sediment yield, summerfallow and the rainfall factor (R).

The spring sediment yield represents a majority of the total annual sediment yield (Table 3.22). Therefore the spring runoff event is the major contributor of sediment to the watershed.

Table 3.22 Regression Variables for Sediment Analysis

Year	Sed-A*	Sed-S	R_t**	R_s	Sf ($x10^3$ ha)
1960	17993	14281	35.39	4.53	115
1961	162	51	15.95	4.17	114
1962	1485	1446	71.77	6.41	110
1963	1320	831	65.10	5.06	109
1964	1031	838	265.00	4.97	109
1965	3814	2144	39.46	4.10	100
1966	13752	7772	33.71	2.94	100
1967	18445	17946	22.63	6.17	114
1968	1659	1570	20.47	3.89	115
1969	6589	6177	39.31	5.11	121
1970	24157	18229	40.74	4.26	164
1971	15190	12314	15.41	3.90	105
1972	11035	9550	12.22	4.31	107
1973	901	118	59.22	3.45	101
1974	60820	40933	15.08	7.59	100
1975	24378	11958	46.18	6.75	110
1976	32178	12752	25.02	6.66	126

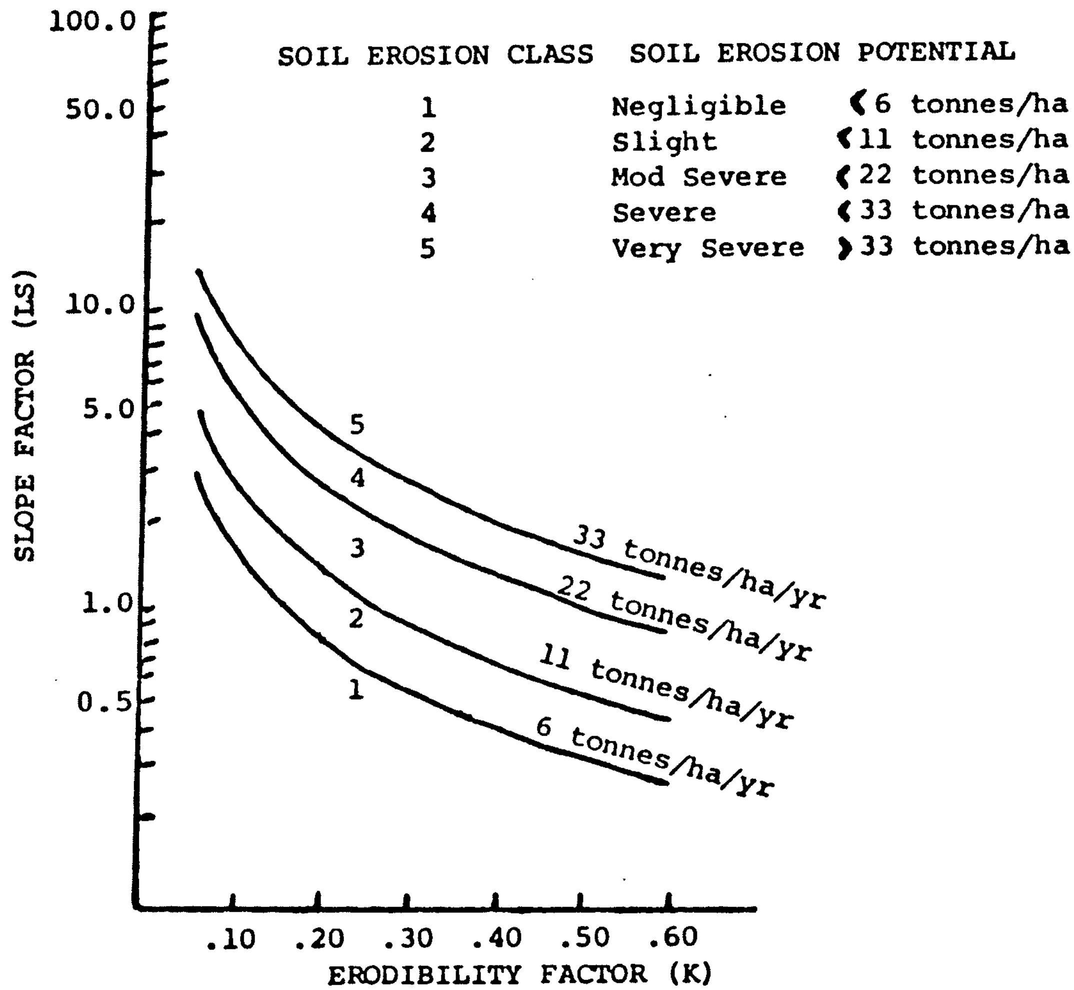
Model***	R	T for H_0	Significance
Sed-A = Rt	0.10	-1.300	not significant
Sed-S = Rs	0.30	2.516	significant (95% CI)
Sed-A = Sf	0.015	0.481	not significant
Sed-S = Sf	0.018	0.529	not significant
Sed-A = Rt Sf	0.011	Rt: -1.237	not significant
		Sf: 0.417	not significant
Sed-S = Rs Sf	0.312	Rs: 2.442	significant (95% CI)
		Sf: 0.547	not significant

* from Penner and Oshway (1983)
** from Steele (1979)
*** Sed-A = Annual sediment load; Sed-S = Spring sediment load
Rt = Annual rainfall factor; Rs = Spring rainfall factor
Sf = summerfallow

3.5.4 Soil Loss Discussion

The estimates of the soil erosion and sediment delivery estimates for the two creeks do not indicate a high risk of soil erosion on a sub-watershed basis. The combined K and LS factors can be used as a relative indicator of water erosion potential. The KLS values obtained for the two creeks were assigned a soil erosion class developed by Wall et al. (1981) (Figure 3.31). Only HU 7 and combined HU 1+2 in Silver Creek showed any risk greater than negligible (Table 3.23). HU 7 in Silver Creek had a water erosion risk of slight to moderate with an estimated potential annual soil loss of 12 - 22 t/ha. HU 1+2 had the potential for a loss of 6 - 11 t/ha., which was considered to constitute very slight to slight risk. An investigation of water erosion on soil associates in the Valley River indicated there was a problem only where topographic features such as hills and knolls were cultivated (Jenkins 1983).

Eiler's (in press) estimated USLE parameters at a 1:1 million scale for soil erosion risk in Manitoba. Silver and Pleasant Valley Creeks are in polygons 126 and 128 of his risk map. The factors Eilers computed compare relatively well with the data for the two study watersheds. The erosion classes for the study area are slight (Table 3.24).



[1]Wall, G.J., Dickinson, W.T. and Grevel, J.W. (1981)

Figure 3.31: Soil erodibility and slope constraints on soil loss from small grain crops[1].

Table 3.23 **Soil Erosion Risk**

Stream	HU	K	LS	KLS	Soil Erosion Class	Potential
Pleasant Valley	1	0.184	0.721	0.1327	1	Negligible < 6 t/ha
	2	0.129	0.452	0.0598	1	Negligible < 6 t/ha
	3	0.182	0.452	0.0823	1	Negligible < 6 t/ha
	4	0.155	0.982	0.1522	1	Negligible < 6 t/ha
	5	0.155	0.632	0.0980	1	Negligible < 6 t/ha
	6	0.189	0.499	0.0943	1	Negligible < 6 t/ha
	7	0.168	0.596	0.1001	1	Negligible < 6 t/ha
	8	0.201	0.382	0.0768	1	Negligible < 6 t/ha
Silver	1&2	0.140	1.217	0.1704	2	Slight < 11 t/ha
	3&4	0.140	0.559	0.0783	1	Negligible < 6 t/ha
	5&6	0.140	0.626	0.0876	1	Negligible < 6 t/ha
	7	0.140	2.240	0.3136	3	Moderate < 22 t/ha
	8	0.159	0.373	0.0593	1	Negligible < 6 t/ha
	9	0.162	0.278	0.0450	1	Negligible < 6 t/ha

Table 3.24 **Comparison of Soil Erosion Potentials**

Map Unit or Stream	R	K	LS	RKLS	Erosion Class
128*	66.5	0.22	0.22	3.2	Slight
126*	66.5	0.26	0.30	5.2	Slight
Pleasant V.	48.4	0.17	0.66	5.4	
Silver	48.4	0.15	0.87	6.3	

* From: Eilers (in press)

The current study applied the USLE equation to two sub-watersheds of Valley River. The study indicated the impact land clearing and land management can have on soil loss and movement as demonstrated by Pleasant Valley and Silver Creeks. Pleasant Valley Creek lost 3 - 4 times as much soil as Silver Creek. The study also identified hydrologic units with greatest soil loss potential. Agricultural development between 1948 and 1980 appears to have caused an increase of 16.4% in soil loss on Silver Creek and a 49.7% increase in soil loss on Pleasant Valley Creek.

3.5.4.1 Soil Loss Tolerances

Soil loss tolerances for Manitoba have not been established. The tolerance level implies that a given field can sustain productivity with an annual soil loss up to the specified tolerance. Soil is normally regenerated by weathering of parent material and deposition by eolian and alluvial processes (Logan 1977). The acceptable level of soil loss is quite varied and is dependant on many factors involved in soil regeneration. The main factor in determining soil loss tolerances is the thickness of topsoil.

The SCS provides guidelines for determining tolerances (Wischmeier and Smith 1978). Using SCS tables all the soils in the study area have an acceptable annual soil loss tolerance of 6.7 - 9.0 t/ha. (Table 3.25). The HUs in the two study creeks all have annual soil losses below 9.0 t/ha. even under poor land management (Table 3.18). HU 4 in Pleasant Valley Creek was the only HU over 6.7 t/ha.

The watershed averaging technique used in calculating soil loss masks the actual field losses. Since tolerances were developed for field level study and the USLE was applied on a HU scale in this study, the tolerances do not apply to the results obtained in Silver and Pleasant Valley Creeks. The results are more relevant to water quality and sedimentation analysis. Tolerances for water quality have not been determined for Manitoba. In general, watershed soil loss tolerances will be lower than field losses.

Table 3.25 Soil Loss Tolerances For representative soils in Valley River Watershed

Soil Series	Depth of Solum (cm)	C Horizon Texture	T value (t/ha/yr)
Blackstone	50 - 76	C - CL	9.0
Dutton	> 76	Si - CL	9.0
Duck Mtn.	< 76	Till	6.7 - 9.0
Gilbert	30 - 76	CL	9.0
Grifton	thin	CL	6.7
Erickson	N.A.	CL	9.0

The largest soil loss does not necessarily mean the greatest sediment yield, both HUs 1 and 4 drain into marshland which act as sediment traps. The sediment delivered to the stream from the excessive soil erosion probably never reaches the Valley River. The time series data (Table 3.18) indicates that the reduction in average annual soil loss is due to reduction in the practice of summerfallow. The figures are indicative of the soil loss reduction through the elimination of Sf in the crop rotation.

3.5.5 Sediment Yield Discussion

The preceding estimates of soil loss on two sub-watersheds indicated the large impact land use can have on soil movement or loss and consequently sediment delivery and yield. Pleasant Valley Creek lost 3 - 4 times as much soil as Silver Creek due to land use and extent of agri-development. Sediment yield ranged from 0.25 - 2.76 t/ha. on Pleasant Valley and 0.13 - 0.87 t/ha. on Silver Creek. The Manitoba-wide estimate for sediment yield was 0.20 - 0.009 t/ha./yr. based on 5% delivery ratio estimated by Coote (1983). The Williams formula over-estimates sediment yield substantially when compared to that. However, the delivery in the current study is based on a storm with a 10 year return period. The data may more importantly indicate the high amounts of erosion and sediment delivery that can occur from a large storm.

Water quality data (Hughes 1985) indicate that more soil enters Pleasant Valley Creek than Silver Creek. Certain water quality parameters are indicative of the increased soil load caused by land use alteration or extent. Total phosphorus (TP) was higher on average in Pleasant Valley than Silver Creek (Table 3.25). TP was higher on Pleasant Valley Creek than on any other station in Valley River watershed. Phosphorus can be associated with increased soil or sediment delivery to a stream (Schlosser and Karr 1980). Phosphorus adheres strongly to soil particles and is easily transported with the soil to a stream (Hynes 1970). Thus, the increased phosphorus loading could be accounted for by the increased sediment load.

Soil particles are not the only vehicle for phosphorus to enter a stream, but the total phosphorus (TP) data combined with other water quality parameters such as turbidity, can suggest that sediment is probably delivered from upland sources. Pleasant Valley had significantly higher values for TDS and TP than Silver Creek stations (Table 3.26).

Although land clearing and land management can have a significant impact on soil loss and sediment delivery, they are not the only sources of sediment in streams. Stream channel and bank erosion, bank trampling by livestock, and ford crossings all contribute to the sediment load of a stream. The occurrence of these potential sediment sources was investigated on the Valley River.

A livestock survey in 1983 showed 36 feedlots bordered the Valley River and its tributaries. There were 1507 livestock animals present in the feedlots at the time of the survey (O'Connor pers. comm.). A stream survey conducted the previous year by the author indicated some potential problems associated with the feedlots and livestock access to the river. The problems were:

1) dumping of animal wastes directly into the river
2) physical evidence of feedlot wastes in the river
3) bank trampling and slumping
4) barns and manure piles below the high water mark.

Table 3.26 **Water Quality Parameters for Valley River**[1]

Station	TDS [2] (mg/l)	Turbidity (NTU)	Total Phosphorus (mg/l)
Silver Ck. (upper)	356 ± 104[3]	2.6 ± 1.5	0.03 ± 0.01
Silver Ck. (lower)	425 ± 107	3.9 ± 3.1	0.06 ± 0.05
Pleasant Valley Ck.	491 ± 116	5.2 ± 2.6	0.15 ± 0.11

1. Source: Manitoba Dept. Environ., Enviromental Control Br
2. TDS = total dissolved solids.
3. ± indicates standard error of estimate

In all 34 sample sections of the Valley River were surveyed and almost all of them had some form of bank erosion which caused sediment to enter the stream. Not all of the observed erosion was man-induced, but it indicated good potential for adding to the sediment load of the river.

Particle size analysis from the sediment station near the south of the Valley River revealed that most of the suspended sediment was silt and clay (55% silt, 43% clay, 2% sand) (WSC 1983). Sediment in the silt and clay sized range have been associated with siltation on walleye spawning beds in the Valley River (Gaboury 1985).

Generally, it is hypothesized that sediment in this size range is source limited and that stream capacity to transport the sediment is greater than the supply. The occurrence of silt and clay sized particles suspended in surface waters is a function of land use and associated erosion and not of stream transport capacity (Mulkey and Falco 1977). Theory, observation and modelling, therefore, indicates that land use has definitely contributed to the sediment load in the Valley River. The magnitude of the loading is illustrated by comparisons between Pleasant Valley and Silver Creeks (Table 3.21).

The Valley River although impacted by man's activities, has not been as seriously affected as other watersheds draining into Lake Dauphin. The Lake Dauphin Sedimentation Study (Penner and Oshway 1982), showed the Valley River to have the second lowest sediment contribution to Lake Dauphin of the 8 rivers tested. The Ochre and Vermilion Rivers contributed up to 6 times as much sediment volume as Valley River on an average annual basis. It is interesting to note that the reason the Fisheries Branch chose the Valley River for study was because it still had a sizeable spawning run of walleye. The effect of sediment on the Valley River fishery may not be as severe as in surrounding watersheds, but the potential for further degradation of instream spawning habitat is present.

CHAPTER IV CONCLUSIONS AND RECOMMENDATIONS

Walleye populations in Lake Dauphin have declined significantly since 1948. An investigation of walleye reproductive habitat in the drainage area surrounding the Lake indicated that spawning habitat had been degraded. Agricultural development was a suspected cause. The physical impacts of agri-development on the hydrologic regime, soil loss and sediment delivery were then investigated as possible sources of habitat degradation.

The Valley River watershed has undergone extensive land development for agriculture since 1948. Agri-development included clearing of land for cultivation, installation of drains, and stream channelization. These developments all contribute to alterations in the hydrologic regime, soil erosion and loss, sediment load and delivery, and water quality. An attempt was made at quantifying these changes for parts of the Valley River watershed.

4.1 CONCLUSIONS

1) The major findings of the land use analysis were the general increase in cultivated acreage, the decrease in woodlands and wetlands, and the decrease in summerfallow after 1969. The major overall change in land use was in the development of land for agriculture.

The greatest change in land use was in the period 1948-69, probably due to a post war expansion in agriculture. Also by 1969 the rate of clearing or reclaiming land for cultivation had slowed due to limits on the availability of suitable land. By 1969 70% of the area was considered improved.

Generally, the downstream sub-watersheds, 7-9, were the most developed for agriculture and were subject to the greatest development pressure. Sub-watershed 7 had the greatest woodland loss, the highest incidence of summerfallowing up to 1969, and the total loss of wetland by 1980. Sub-watershed 7 underwent the greatest land use alteration and development of all the sub-watersheds in the study area.

Land use analysis in the riparian zone showed similar trends as in the rest of the watershed. Agricultural land increased , wetland and woodland decreased. Agricultural land nearly doubled in the zone. In 1948 it represented 16.9% and by 1980 it represented 32.7%. Wetland were almost eliminated during the same time period. In 1980 only 11 of 120 hectares of wetland remained in the zone.

2) Hydrograph analysis was performed on existing hydrometric information. Hydrographs were normalized, unitized and averaged. K factors were also determined for the recession limbs of all the hydrographs and analysed. The results of all tests clearly indicated the hydrologic regime

of the watershed had changed since 1913. Spring runoff hydrographs exhibited higher peak flows, faster time to peak, steeper recession limbs and a greater volume of runoff in recent time periods than in earlier periods. The peak flow rate was 65% higher in the period 1965-81 than in the period 1913-28. Multiple regression analysis also predicted peak flow increases, based on climatological and land use data. It is concluded that agricultural development, including land clearing and drainage was responsible for the observed hydrologic changes.

3) Hydrologic modelling was used to synthesize storm hydrographs under different land uses in 2 sub-watersheds of the Valley River. The results of the model for land use changes between 1948-1981 suggested an 8.0% increase in peak flow and a 5.5% increase in runoff on Silver Creek, which was relatively undeveloped for agriculture. The other sub-watershed, Pleasant Valley Creek, showed an 11.8% increase in peak flow and a 11.1% increase in runoff over the same time period. Pleasant Valley Creek was slightly larger in area than Silver Creek, but it was more developed for agriculture.

The SCS and HYMO models produced much larger peak flows and runoff volumes for Pleasant Valley Creek than Silver Creek. Pleasant Valley watershed was only 22% larger than Silver but produced peak flows up 3 times, and runoff volumes up to 2 times that of Silver Creek. The extent of agricultural land use was the main reason for the difference.

Hydrologic modelling was also carried out at the HU level on the same two sub-watersheds. The hydrographs developed from the design storm showed HUs with the greatest runoff potential, based on topography and land use. The largest peak flow rate and runoff volume occurred on HU 7 in Pleasant Valley. In Silver Creek watershed HU 8 had the largest peak flow and HU 9 had the largest runoff volume.

4) The USLE was used to evaluate soil loss due to land use change between 1948-80 on Pleasant Valley and Silver Creek watersheds. Soil loss increased on both watersheds due to agricultural land use. A peak in soil loss occurred in 1969 which corresponded to a peak in summerfallow use. Soil loss actually declined between 1969-1980, but there was still an overall increase between 1948-1980. Pleasant Valley lost up to 4 times more soil in total than Silver Creek due to the extent of agricultural land use on the former.

Estimates were made of sediment yield from synthetic storm runoff generated by SCS and HYMO models for Silver and Pleasant Valley Creeks. The model suggested that Pleasant Valley Creek had up to 11 times the total sediment yield of Silver Creek in 1948,1969 and 1980, although the former was only 23% larger in drainage area. The large difference was mainly due to the larger storm runoff hydrographs produced on Pleasant Valley and the larger percentage of land under cultivation in Pleasant Valley watershed. Silver Creek on the other hand has 77% of its drainage area in native forest.

Sediment yield increased due to changes in agricultural land use over time on both Pleasant Valley and Silver Creeks. The sediment yield peaked in 1969 mainly as a result of the increased use of summerfallow as noted above. Yield decreased between 1969 and 1980 on both watersheds, but increased overall between 1948-1980. Summerfallow area was a major factor in determining sediment yield on both watersheds.

5) Areas with the highest soil loss and/or sediment yield were identified in Pleasant Valley and Silver Creeks. HUs 1 & 4 on Pleasant Valley Creek exhibited high rates of soil loss on an average annual basis (t/ha). In terms of impact on the Valley River HUs 6-8 were the most significant, because of their proximity to the Valley River, and extent of agricultural development. HU 8 on Silver Creek produced more sediment in the model on less area of agricultural land than adjacent HU 9. Therefore HU 8 was considered an area of greatest potential for high rates of soil loss and sediment delivery on Silver Creek watershed.

Soil erosion risk was assessed using three factors from the USLE. The soil erodibility factor K was combined with the slope length factor L and the slope steepness factor S to produce a measure of soil erosion risk. HU 7 on Silver Creek, which is in a forested area, had a risk of moderate, which was less than 22 t/ha. It was the only HU with a risk greater than slight.

4.2 RECOMMENDATIONS

1). The study has documented major changes in land use in the watershed since 1948. Increases in peak flow and runoff volume associated with land use changes on the Valley River and its sub-watersheds should be mitigated by reducing the area of summerfallow, protecting the remaining wetland areas, and encouraging the rehabilitation of wetlands for water storage on private land.

Comprehensive water management plans should be developed for the existing water control structures on the Valley River system to mitigate peaks in spring runoff through headwater storage and control. In particular, Jackfish Lake, Burrows Lake and Pleasant Valley Reservoir require improved water management plans to reduce downstream peak flows in high runoff years, and enhance downstream flows for fish spawning in spring.

2). Soil loss and sediment yield have been shown to increase in response to changes in agricultural land use on two sub-watersheds of Valley River. To protect the soil base of the area and reduce the input of sediment into local drainage soil conservation measures should be practiced. Specifically, hills, knolls and fields should be tilled along the land contour to slow down surface runoff and reduce erosion. Field waterways should be grassed and not cultivated. Buffer strips of 4-5m should be established along all natural and artificial waterways to act as sediment filtration areas and to protect stream banks and the riparian zone (Switzer-House 1983). Summerfallow should be discouraged in all areas. No land should be left fallow in the flood plain of the Valley River and its tributaries.

Soil conservation measures should be directed in the first instance to areas with the highest soil loss potential identified in both Pleasant Valley and Silver Creeks. Areas identified as having the greatest potential for soil loss due to extent of development, topographic factors or soil erodibility should be investigated on a field scale and appropriate soil conservation measures applied.

3). The riparian zone bordering the Valley River has undergone major developmental changes since 1948. Heavy livestock concentration, cultivation, and wetland removal in the zone, have all contributed to the degradation of the instream environment. The buffer or riparian zone is extremely important to the integrity of the lentic environment. Therefore, it is recommended that buffer zones of 4-5m from high water marks be established along all natural waterways in the Valley River watershed. Appropriate species of vegetation that are effective against erosion should be planted in the buffer zones. Also livestock should be kept out of buffer zones and watered only where access to the stream is limited and banks are protected.

4). Soil and water conservation are best accomplished under a watershed planning board. It is recommended that the Valley River Watershed be incorporated into an institutional framework for the delivery of comprehensive soil and water management programs.

4.3 RECOMMENDATIONS FOR FURTHER RESEARCH

1). Watershed hydrologic modelling is important for assessment work and future evaluation of soil and water conservation. It is recommended that further development of models continue by establishing test and research hydrologic units in the Valley River watershed. This would require meteorological and hydrometric data collection on a year round basis in order to calibrate hydrologic models.

2). In conjunction with test hydrologic units, soil conservation measures should be tested and evaluated by using the USLE and monitoring stream sediment loads. The USLE should be used at field scale level within the HUs.

3). A regional data base should be established for the Valley River that combines SCS parameters with satellite images of the area. Land use changes and the impact on the hydrologic regime could then be easily monitored. The GIS (Geographic Information System) computer software has the capability to perform this function.

4). Economic evaluation of agricultural land development and use should be performed on sub-watersheds in the Valley River watershed. Social benefit-cost analysis should be performed and include all effects on the Lake Dauphin fishery.

GLOSSARY

CN value - Curve Number for use in the Soil Conservation Service runoff equation. CN values range between 1 and 100, and represent the potential for runoff on a given area of land.

HUs - Hydrologic Units as defined by the SCS National Engineering Handbook, Section 4, Hydrology (1972).

R,K,LS,C,P - are Universal Soil Loss Equation factors (see Chapter 2 Methods).

SCS - Soil Conservation Service

Tp - Time to peak flow from the onset of rainfall runoff

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PERSONAL COMMUNICATIONS

Eilers, R.G., Soil Scientist, Soil Science Dept., Univ. of Mantioba, Winnipeg.

Levesque, A.N., Engineer, Engineering and Construction Branch, Manitoba Dept. of Natural Resources, Dauphin.

O'Connor, J.F., Chief of Biological Services, Fisheries Branch, Manitoba Dept. of Natural Resources, Winnipeg.

Valiant, H., Fisheries Biologist, Fisheries Branch, Manitoba Dept. of NAtural Resources, Dauphin.

Warkentin, A., Hydrometeorologist, Water Resources Branch, Manitoba Dept. of Natural Resources, Winnipeg

APPENDIX I

VALLEY RIVER

LAND USE DATA

Total Watershed Area

SUB-WATERSHED 1

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	3.6	0.0	3093.5	6818.8	2921.8	5185.3	86782.6	5270.6	4847.1
1969	0.0	0.0	6634.7	11445.8	5031.9	3788.0	78347.8	5125.5	4549.6
1980	0.0	0.0	700.4	19692.7	2194.8	4597.6	79505.5	3944.0	4288.8

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-3.6	0.0	3541.2	4627.0	2110.1	-1397.3	-8434.8	-145.1	-297.5
1969-1980	0.0	0.0	-5934.3	8246.9	-2837.1	809.6	1157.7	-1181.5	-260.8
1949-1980	-3.6	0.0	-2393.1	12873.9	-727.0	-587.7	-7277.1	-1326.6	-558.3

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	114.47	67.86	72.22	-26.95	-9.72	-2.75	-6.14
1969-1980	0.00	0.00	-89.44	72.05	-56.38	21.37	1.48	-23.05	-5.73
1948-1980	0.00	0.00	-77.36	188.80	-24.88	-11.33	-8.39	-25.17	-11.52

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.00	0.00	2.69	5.93	2.54	4.51	75.51	4.59	4.22
1969	0.00	0.00	5.77	9.96	4.38	3.30	68.17	4.46	3.96
1980	0.00	0.00	0.61	17.14	1.91	4.00	69.18	3.43	3.73

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-0.00	0.00	3.08	4.03	1.84	-1.22	-7.34	-0.13	-0.26
1969-1980	0.00	0.00	-5.16	7.18	-2.47	0.70	1.01	-1.03	-0.23
1948-1980	-0.00	0.00	-2.08	11.20	-0.63	-0.51	-6.33	-1.15	-0.49

TOTAL LAND AREA IN HECTARES FOR 1948 = 114923.7

TOTAL LAND AREA IN HECTARES FOR 1969 = 114923.7

TOTAL LAND IN HECTARES FOR 1980 = 114923.8

TOTAL CLASSIFIED ACREAGE FOR 1948 = 114923.2

TOTAL CLASSIFIED ACREAGE FOR 1969 = 114923.3

TOTAL CLASSIFIED ACREAGE FOR 1980 = 114923.7

SUB-WATERSHED 2

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.0	0.0	2439.5	4853.7	1477.1	4892.6	13730.1	2111.4	928.1
1969	0.0	0.0	3756.2	7780.8	3383.1	3039.5	10142.3	1664.0	666.4
1980	0.0	0.0	472.1	11299.8	1329.8	4758.1	10940.7	536.7	1095.3

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.0	0.0	1316.7	2927.1	1906.0	-1853.1	-3587.8	-447.4	-261.7
1969-1980	0.0	0.0	-3284.1	3519.0	-2053.3	1718.6	798.4	-1127.3	428.9
1949-1980	0.0	0.0	-1967.4	6446.1	-147.3	-134.5	-2789.4	-1574.7	167.2

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	53.97	60.31	129.04	-37.88	-26.13	-21.19	-28.20
1969-1980	0.00	0.00	-87.43	45.23	-60.69	56.54	7.87	-67.75	64.36
1948-1980	0.00	0.00	-80.65	132.81	-9.97	-2.75	-20.32	-74.58	18.02

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.00	0.00	8.02	15.95	4.85	16.08	45.12	6.94	3.05
1969	0.00	0.00	12.34	25.57	11.12	9.99	33.33	5.47	2.19
1980	0.00	0.00	1.55	37.13	4.37	15.63	35.95	1.76	3.60

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.00	0.00	4.33	9.62	6.26	-6.09	-11.79	-1.47	-0.86
1969-1980	0.00	0.00	-10.79	11.56	-6.75	5.65	2.62	-3.70	1.41
1948-1980	0.00	0.00	-6.46	21.18	-0.48	-0.44	-9.17	-5.17	0.55

TOTAL LAND AREA IN HECTARES FOR 1948 = 30432.5

TOTAL LAND AREA IN HECTARES FOR 1969 = 30432.3

TOTAL LAND IN HECTARES FOR 1980 = 30432.5

TOTAL CLASSIFIED ACREAGE FOR 1948 = 30432.5

TOTAL CLASSIFIED ACREAGE FOR 1969 = 30432.3

TOTAL CLASSIFIED ACREAGE FOR 1980 = 30432.5

SUB-WATERSHED 3

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.0	0.0	743.4	1293.1	632.5	200.8	13084.3	808.0	697.3
1969	0.0	0.0	838.6	1732.3	643.2	275.3	12526.2	749.6	694.0
1980	0.0	0.0	284.1	2586.8	177.1	392.8	12668.7	669.0	680.8

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.0	0.0	95.2	439.2	10.7	74.5	-558.1	-58.4	-3.3
1969-1980	0.0	0.0	-554.5	854.5	-466.1	117.5	142.5	-80.6	-13.2
1949-1980	0.0	0.0	-459.3	1293.7	-455.4	192.0	-415.6	-139.0	-16.5

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	12.81	33.96	1.69	37.10	-4.27	-7.23	-0.47
1969-1980	0.00	0.00	-66.12	49.33	-72.47	42.68	1.14	-10.75	-1.90
1948-1980	0.00	0.00	-61.78	100.05	-72.00	95.62	-3.18	-17.20	-2.37

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.00	0.00	4.26	7.41	3.62	1.15	74.94	4.63	3.99
1969	0.00	0.00	4.80	9.92	3.68	1.58	71.75	4.29	3.98
1980	0.00	0.00	1.63	14.82	1.01	2.25	72.56	3.83	3.90

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.00	0.00	0.55	2.52	0.06	0.43	-3.20	-0.33	-0.02
1969-1980	0.00	0.00	-3.18	4.89	-2.67	0.67	0.82	-0.46	-0.08
1948-1980	0.00	0.00	-2.63	7.41	-2.61	1.10	-2.38	-0.80	-0.09

TOTAL LAND AREA IN HECTARES FOR 1948 = 17459.0

TOTAL LAND AREA IN HECTARES FOR 1969 = 17459.0

TOTAL LAND IN HECTARES FOR 1980 = 17459.0

TOTAL CLASSIFIED ACREAGE FOR 1948 = 17459.4

TOTAL CLASSIFIED ACREAGE FOR 1969 = 17459.2

TOTAL CLASSIFIED ACREAGE FOR 1980 = 17459.3

SUB-WATERSHED 4

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.0	0.0	1707.9	3421.0	1195.7	506.7	5679.8	136.6	107.6
1969	0.0	0.0	2073.1	4985.6	1289.9	349.9	3788.9	167.9	100.4
1980	0.0	0.0	575.6	6650.3	645.9	899.5	3783.7	100.4	100.4

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.0	0.0	365.2	1564.6	94.2	-156.8	-1890.9	31.3	-7.2
1969-1980	0.0	0.0	-1497.5	1664.7	-644.0	549.6	-5.2	-67.5	0.0
1949-1980	0.0	0.0	-1132.3	3229.3	-549.8	392.8	-1896.1	-36.2	-7.2

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	21.38	45.74	7.88	-30.95	-33.29	22.91	-6.69
1969-1980	0.00	0.00	-72.23	33.39	-49.93	157.07	-0.14	-40.20	0.00
1948-1980	0.00	0.00	-66.30	94.40	-45.98	77.52	-33.38	-26.50	-6.69

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.00	0.00	13.39	26.82	9.37	3.97	44.53	1.07	0.84
1969	0.00	0.00	16.25	39.09	10.11	2.74	29.70	1.32	0.79
1980	0.00	0.00	4.51	52.14	5.06	7.05	29.66	0.79	0.79

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.00	0.00	2.86	12.27	0.74	-1.23	-14.82	0.25	-0.06
1969-1980	0.00	0.00	-11.74	13.05	-5.05	4.31	-0.04	-0.53	0.00
1948-1980	0.00	0.00	-8.88	25.32	-4.31	3.08	-14.86	-0.28	-0.06

TOTAL LAND AREA IN HECTARES FOR 1948 = 12755.7

TOTAL LAND AREA IN HECTARES FOR 1969 = 12755.7

TOTAL LAND IN HECTARES FOR 1980 = 12755.8

TOTAL CLASSIFIED ACREAGE FOR 1948 = 12755.3

TOTAL CLASSIFIED ACREAGE FOR 1969 = 12755.7

TOTAL CLASSIFIED ACREAGE FOR 1980 = 12755.8

SUB-WATERSHED 5

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.0	1.2	2282.3	4196.8	1971.5	810.5	8478.2	322.5	234.3
1969	0.0	0.0	2854.0	6586.8	1846.2	701.2	5818.0	265.5	225.5
1980	0.0	0.0	1031.4	8905.1	961.9	1041.8	5954.0	183.3	226.8

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.0	-1.2	571.7	2390.0	-125.3	-109.3	-2660.2	-57.0	-8.8
1969-1980	0.0	0.0	-1822.6	2318.3	-884.3	340.6	136.0	-82.2	1.3
1949-1980	0.0	-1.2	-1250.9	4708.3	-1009.6	231.3	-2524.2	-139.2	-7.5

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	25.05	56.95	-6.36	-13.49	-31.38	-17.67	-3.76
1969-1980	0.00	0.00	-63.86	35.20	-47.90	48.57	2.34	-30.96	0.58
1948-1980	0.00	0.00	-54.81	112.19	-51.21	28.54	-29.77	-43.16	-3.20

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.00	0.01	12.47	22.94	10.77	4.43	46.34	1.76	1.28
1969	0.00	0.00	15.60	36.00	10.09	3.83	31.80	1.45	1.23
1980	0.00	0.00	5.64	48.67	5.26	5.69	32.54	1.00	1.24

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.00	-0.01	3.12	13.06	-0.68	-0.60	-14.54	-0.31	-0.05
1969-1980	0.00	0.00	-9.96	12.67	-4.83	1.86	0.74	-0.45	0.01
1948-1980	0.00	-0.01	-6.84	25.73	-5.52	1.26	-13.80	-0.76	-0.04

TOTAL LAND AREA IN HECTARES FOR 1948 = 18297.2

TOTAL LAND AREA IN HECTARES FOR 1969 = 18297.3

TOTAL LAND IN HECTARES FOR 1980 = 18304.3

TOTAL CLASSIFIED ACREAGE FOR 1948 = 18297.3

TOTAL CLASSIFIED ACREAGE FOR 1969 = 18297.2

TOTAL CLASSIFIED ACREAGE FOR 1980 = 18304.3

SUB-WATERSHED 6

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	4.4	0.0	2768.8	6744.6	3510.4	1802.7	16532.5	358.0	261.3
1969	0.0	0.0	4424.9	8664.3	5258.7	2526.6	10549.0	306.0	253.0
1980	0.0	0.0	1749.7	14816.5	1833.7	2433.9	10650.3	230.3	230.8

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-4.4	0.0	1656.1	1919.7	1748.3	723.9	-5983.5	-52.0	-8.3
1969-1980	0.0	0.0	-2675.2	6152.2	-3425.0	-92.7	101.3	-75.7	-22.2
1949-1980	-4.4	0.0	-1019.1	8071.9	-1676.7	631.2	-5882.2	-127.7	-30.5

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	59.81	28.46	49.80	40.16	-36.19	-14.53	-3.18
1969-1980	0.00	0.00	-60.46	71.01	-65.13	-3.67	0.96	-24.74	-8.77
1948-1980	0.00	0.00	-36.81	119.68	-47.76	35.01	-35.58	-35.67	-11.67

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.01	0.00	8.66	21.09	10.98	5.64	51.69	1.12	0.82
1969	0.00	0.00	13.84	27.09	16.44	7.90	32.98	0.96	0.79
1980	0.00	0.00	5.47	46.33	5.73	7.61	33.30	0.72	0.72

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-0.01	0.00	5.18	6.00	5.47	2.26	-18.71	-0.16	-0.03
1969-1980	0.00	0.00	-8.36	19.24	-10.71	-0.29	0.32	-0.24	-0.07
1948-1980	-0.01	0.00	-3.19	25.24	-5.24	1.97	-18.39	-0.40	-0.10

TOTAL LAND AREA IN HECTARES FOR 1948 = 31982.6

TOTAL LAND AREA IN HECTARES FOR 1969 = 31982.5

TOTAL LAND IN HECTARES FOR 1980 = 31945.2

TOTAL CLASSIFIED ACREAGE FOR 1948 = 31982.7

TOTAL CLASSIFIED ACREAGE FOR 1969 = 31982.5

TOTAL CLASSIFIED ACREAGE FOR 1980 = 31945.2

SUB-WATERSHED 7

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	74.6	1.6	4128.8	6926.6	1196.7	1380.6	4816.7	181.9	5.1
1969	82.4	0.0	4584.9	9047.1	2445.6	895.0	1537.3	97.6	22.8
1980	112.5	0.0	820.9	12946.6	952.4	2224.9	1649.9	0.0	5.5

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	7.8	-1.6	456.1	2120.5	1248.9	-485.6	-3279.4	-84.3	17.7
1969-1980	30.1	0.0	-3764.0	3899.5	-1493.2	1329.9	112.6	-97.6	-17.3
1949-1980	37.9	-1.6	-3307.9	6020.0	-244.3	844.3	-3166.8	-181.9	0.4

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	10.46	0.00	11.05	30.61	104.36	-35.17	-68.08	-14.53	347.06
1969-1980	36.53	0.00	-82.10	43.10	-61.06	148.59	7.32	-24.74	-75.88
1948-1980	50.80	0.00	-80.12	86.91	-20.41	61.15	-65.75	-35.67	7.84

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.40	0.01	22.06	37.02	6.40	7.38	25.74	0.97	0.03
1969	0.44	0.00	24.50	48.35	13.07	4.78	8.22	0.52	0.12
1980	0.60	0.00	4.39	69.19	5.09	11.89	8.82	0.00	0.03

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.04	-0.01	2.44	11.33	6.67	-2.60	-17.52	-0.45	0.09
1969-1980	0.16	0.00	-20.11	20.84	-7.98	7.11	0.60	-0.52	-0.09
1948-1980	0.20	-0.01	-17.68	32.17	-1.31	4.51	-16.92	-0.97	0.00

TOTAL LAND AREA IN HECTARES FOR 1948 = 18712.7

TOTAL LAND AREA IN HECTARES FOR 1969 = 18712.8

TOTAL LAND IN HECTARES FOR 1980 = 18712.7

TOTAL CLASSIFIED ACREAGE FOR 1948 = 18712.6

TOTAL CLASSIFIED ACREAGE FOR 1969 = 18712.7

TOTAL CLASSIFIED ACREAGE FOR 1980 = 18712.7

SUB-WATERSHED 8

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	12.9	0.0	2631.9	5877.7	5274.1	1394.5	6909.0	298.1	284.5
1969	12.2	0.0	3666.6	9328.3	4271.3	1751.7	3346.7	117.5	188.4
1980	0.0	0.0	719.8	14081.3	1824.0	2102.5	3696.6	0.0	252.4

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-0.7	0.0	1034.7	3450.6	-1002.8	357.2	-3562.3	-180.6	-96.1
1969-1980	-12.2	0.0	-2946.8	4753.0	-2447.3	350.8	349.9	-117.5	64.0
1949-1980	-12.9	0.0	-1912.1	8203.6	-3450.1	708.0	-3212.4	-298.1	-32.1

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	10.46	0.00	39.31	58.71	-19.01	25.61	-51.56	-14.53	-33.78
1969-1980	36.53	0.00	-80.37	50.95	-57.30	20.03	10.46	-24.74	33.97
1948-1980	50.80	0.00	-72.65	139.57	-65.42	50.77	-46.50	-35.67	-11.28

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.06	0.00	11.60	25.91	23.25	6.15	30.46	1.31	1.25
1969	0.05	0.00	16.16	41.12	18.83	7.72	14.75	0.52	0.83
1980	0.00	0.00	3.17	62.08	8.04	9.27	16.30	0.00	1.11

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-0.00	0.00	4.56	15.21	-4.42	1.57	-15.70	-0.80	-0.42
1969-1980	-0.05	0.00	-12.99	20.95	-10.79	1.55	1.54	-0.52	0.28
1948-1980	-0.06	0.00	-8.43	36.17	-15.21	3.12	-14.16	-1.31	-0.14

TOTAL LAND AREA IN HECTARES FOR 1948 = 22682.9

TOTAL LAND AREA IN HECTARES FOR 1969 = 22682.9

TOTAL LAND IN HECTARES FOR 1980 = 22676.6

TOTAL CLASSIFIED ACREAGE FOR 1948 = 22682.7

TOTAL CLASSIFIED ACREAGE FOR 1969 = 22682.7

TOTAL CLASSIFIED ACREAGE FOR 1980 = 22676.6

SUB-WATERSHED 9

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	131.8	6.6	1934.0	4484.0	3515.7	1247.7	4937.6	59.5	0.0
1969	118.7	0.0	2517.0	7482.4	2423.7	950.2	2777.7	46.3	1.0
1980	97.8	0.0	912.3	9486.0	1348.0	1638.5	2834.7	0.0	0.0

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-13.1	-6.6	583.0	2998.4	-1092.0	-297.5	-2159.9	-13.2	1.0
1969-1980	-20.9	0.0	-1604.7	2003.6	-1075.7	688.3	57.0	-46.3	-1.0
1949-1980	-34.0	-6.6	-1021.7	5002.0	-2167.7	390.8	-2102.9	-59.5	0.0

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	-9.94	0.00	30.14	66.87	-31.06	-23.84	-43.74	-14.53	-33.78
1969-1980	-17.61	0.00	-63.75	26.78	-44.38	72.44	2.05	-24.74	33.97
1948-1980	-25.80	0.00	-52.83	111.55	-61.66	31.32	-42.59	-35.67	-11.28

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.81	0.04	11.85	27.48	21.55	7.65	30.26	0.36	0.00
1969	0.73	0.00	15.43	45.86	14.85	5.82	17.02	0.28	0.01
1980	0.60	0.00	5.59	58.14	8.26	10.04	17.37	0.00	0.00

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-0.08	-0.04	3.57	18.38	-6.69	-1.82	-13.24	-0.08	0.01
1969-1980	-0.13	0.00	-9.83	12.28	-6.59	4.22	0.35	-0.28	-0.01
1948-1980	-0.21	-0.04	-6.26	30.66	-13.28	2.40	-12.89	-0.36	0.00

TOTAL LAND AREA IN HECTARES FOR 1948 = 16316.9

TOTAL LAND AREA IN HECTARES FOR 1969 = 16316.9

TOTAL LAND IN HECTARES FOR 1980 = 16317.0

TOTAL CLASSIFIED ACREAGE FOR 1948 = 16316.9

TOTAL CLASSIFIED ACREAGE FOR 1969 = 16317.0

TOTAL CLASSIFIED ACREAGE FOR 1980 = 16317.3

STATEMENTS EXECUTED= 2678

Study Area

SUB-WATERSHED 1

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	3.6	0.0	3093.5	6818.8	2921.8	5185.3	16654.6	1374.6	951.1
1969	0.0	0.0	6634.7	11445.8	5031.9	3788.0	8219.8	1229.5	653.6
1980	0.0	0.0	700.4	19692.7	2194.8	4597.6	9377.5	48.0	392.8

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-3.6	0.0	3541.2	4627.0	2110.1	-1397.3	-8434.8	-145.1	-297.5
1969-1980	0.0	0.0	-5934.3	8246.9	-2837.1	809.6	1157.7	-1181.5	-260.8
1949-1980	-3.6	0.0	-2393.1	12873.9	-727.0	-587.7	-7277.1	-1326.6	-558.3

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	114.47	67.86	72.22	-26.95	-50.65	-10.56	-31.28
1969-1980	0.00	0.00	-89.44	72.05	-56.38	21.37	14.08	-96.10	-39.90
1948-1980	0.00	0.00	-77.36	188.80	-24.88	-11.33	-43.69	-96.51	-58.70

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.01	0.00	8.36	18.43	7.90	14.01	45.01	3.71	2.57
1969	0.00	0.00	17.93	30.93	13.60	10.24	22.21	3.32	1.77
1980	0.00	0.00	1.89	53.22	5.93	12.42	25.34	0.13	1.06

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-0.01	0.00	9.57	12.50	5.70	-3.78	-22.79	-0.39	-0.80
1969-1980	0.00	0.00	-16.04	22.29	-7.67	2.19	3.13	-3.19	-0.70
1948-1980	-0.01	0.00	-6.47	34.79	-1.96	-1.59	-19.67	-3.59	-1.51

TOTAL LAND AREA IN HECTARES FOR 1948 = 37003.3

TOTAL LAND AREA IN HECTARES FOR 1969 = 37003.7

TOTAL LAND IN HECTARES FOR 1980 = 37003.8

TOTAL CLASSIFIED ACREAGE FOR 1948 = 37003.3

TOTAL CLASSIFIED ACREAGE FOR 1969 = 37003.3

TOTAL CLASSIFIED ACREAGE FOR 1980 = 37003.8

SUB-WATERSHED 2

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.0	0.0	2439.5	4853.7	1477.1	4892.6	10583.2	1936.6	753.3
1969	0.0	0.0	3756.2	7780.8	3383.1	3039.5	6995.4	1489.2	491.6
1980	0.0	0.0	472.1	11299.8	1329.8	4758.1	7793.8	361.9	920.5

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.0	0.0	1316.7	2927.1	1906.0	-1853.1	-3587.8	-447.4	-261.7
1969-1980	0.0	0.0	-3284.1	3519.0	-2053.3	1718.6	798.4	-1127.3	428.9
1949-1980	0.0	0.0	-1967.4	6446.1	-147.3	-134.5	-2789.4	-1574.7	167.2

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	53.97	60.31	129.04	-37.88	-33.90	-23.10	-34.74
1969-1980	0.00	0.00	-87.43	45.23	-60.69	56.54	11.41	-75.70	87.25
1948-1980	0.00	0.00	-80.65	132.81	-9.97	-2.75	-26.36	-81.31	22.20

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.00	0.00	9.06	18.02	5.48	18.16	39.29	7.19	2.80
1969	0.00	0.00	13.94	28.89	12.56	11.28	25.97	5.53	1.83
1980	0.00	0.00	1.75	41.95	4.94	17.66	28.93	1.34	3.42

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.00	0.00	4.89	10.87	7.08	-6.88	-13.32	-1.66	-0.97
1969-1980	0.00	0.00	-12.19	13.06	-7.62	6.38	2.96	-4.19	1.59
1948-1980	0.00	0.00	-7.30	23.93	-0.55	-0.50	-10.36	-5.85	0.62

TOTAL LAND AREA IN HECTARES FOR 1948 = 26936.0

TOTAL LAND AREA IN HECTARES FOR 1969 = 26935.8

TOTAL LAND IN HECTARES FOR 1980 = 26936.0

TOTAL CLASSIFIED ACREAGE FOR 1948 = 26936.0

TOTAL CLASSIFIED ACREAGE FOR 1969 = 26935.8

TOTAL CLASSIFIED ACREAGE FOR 1980 = 26936.0

SUB-WATERSHED 3

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.0	0.0	743.4	1293.1	632.5	200.8	1042.3	139.0	28.3
1969	0.0	0.0	838.6	1732.3	643.2	275.3	484.2	80.6	25.0
1980	0.0	0.0	284.1	2586.8	177.1	392.8	626.7	0.0	11.8

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.0	0.0	95.2	439.2	10.7	74.5	-558.1	-58.4	-3.3
1969-1980	0.0	0.0	-554.5	854.5	-466.1	117.5	142.5	-80.6	-13.2
1949-1980	0.0	0.0	-459.3	1293.7	-455.4	192.0	-415.6	-139.0	-16.5

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	12.81	33.96	1.69	37.10	-53.55	-23.10	-11.66
1969-1980	0.00	0.00	-66.12	49.33	-72.47	42.68	29.43	-75.70	-52.80
1948-1980	0.00	0.00	-61.78	100.05	-72.00	95.62	-39.87	-81.31	-58.30

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.00	0.00	18.22	31.70	15.51	4.92	25.55	3.41	0.69
1969	0.00	0.00	20.56	42.47	15.77	6.75	11.87	1.98	0.61
1980	0.00	0.00	6.96	63.41	4.34	9.63	15.36	0.00	0.29

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.00	0.00	2.33	10.77	0.26	1.83	-13.68	-1.43	-0.08
1969-1980	0.00	0.00	-13.59	20.95	-11.43	2.88	3.49	-1.98	-0.32
1948-1980	0.00	0.00	-11.26	31.71	-11.16	4.71	-10.19	-3.41	-0.40

TOTAL LAND AREA IN HECTARES FOR 1948 = 4079.2

TOTAL LAND AREA IN HECTARES FOR 1969 = 4079.2

TOTAL LAND IN HECTARES FOR 1980 = 4079.3

TOTAL CLASSIFIED ACREAGE FOR 1948 = 4079.4

TOTAL CLASSIFIED ACREAGE FOR 1969 = 4079.2

TOTAL CLASSIFIED ACREAGE FOR 1980 = 4079.3

SUB-WATERSHED 4

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.0	0.0	1707.9	3421.0	1195.7	506.7	3873.3	36.2	7.2
1969	0.0	0.0	2073.1	4985.6	1289.9	349.9	1982.4	67.5	0.0
1980	0.0	0.0	575.6	6650.3	645.9	899.5	1977.2	0.0	0.0

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.0	0.0	365.2	1564.6	94.2	-156.8	-1890.9	31.3	-7.2
1969-1980	0.0	0.0	-1497.5	1664.7	-644.0	549.6	-5.2	-67.5	0.0
1949-1980	0.0	0.0	-1132.3	3229.3	-549.8	392.8	-1896.1	-36.2	-7.2

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	21.38	45.74	7.88	-30.95	-48.82	-23.10	-11.66
1969-1980	0.00	0.00	-72.23	33.39	-49.93	157.07	-0.26	-75.70	-52.80
1948-1980	0.00	0.00	-66.30	94.40	-45.98	77.52	-48.95	-81.31	-58.30

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.00	0.00	15.89	31.83	11.12	4.71	36.04	0.34	0.07
1969	0.00	0.00	19.29	46.38	12.00	3.26	18.44	0.63	0.00
1980	0.00	0.00	5.36	61.87	6.01	8.37	18.40	0.00	0.00

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.00	0.00	3.40	14.56	0.88	-1.46	-17.59	0.29	-0.07
1969-1980	0.00	0.00	-13.93	15.49	-5.99	5.11	-0.05	-0.63	0.00
1948-1980	0.00	0.00	-10.53	30.04	-5.12	3.65	-17.64	-0.34	-0.07

TOTAL LAND AREA IN HECTARES FOR 1948 = 10748.4

TOTAL LAND AREA IN HECTARES FOR 1969 = 10748.4

TOTAL LAND IN HECTARES FOR 1980 = 10748.5

TOTAL CLASSIFIED ACREAGE FOR 1948 = 10748.0

TOTAL CLASSIFIED ACREAGE FOR 1969 = 10748.4

TOTAL CLASSIFIED ACREAGE FOR 1980 = 10748.5

SUB-WATERSHED 5

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.0	1.2	2282.3	4196.8	1971.5	810.5	5214.8	141.2	53.0
1969	0.0	0.0	2854.0	6586.8	1846.2	701.2	2554.6	84.2	44.2
1980	0.0	0.0	1031.4	8905.1	961.9	1041.8	2690.6	2.0	45.5

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.0	-1.2	571.7	2390.0	-125.3	-109.3	-2660.2	-57.0	-8.8
1969-1980	0.0	0.0	-1822.6	2318.3	-884.3	340.6	136.0	-82.2	1.3
1949-1980	0.0	-1.2	-1250.9	4708.3	-1009.6	231.3	-2524.2	-139.2	-7.5

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	25.05	56.95	-6.36	-13.49	-51.01	-40.37	-16.60
1969-1980	0.00	0.00	-63.86	35.20	-47.90	48.57	5.32	-97.62	2.94
1948-1980	0.00	0.00	-54.81	112.19	-51.21	28.54	-48.40	-98.58	-14.15

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.00	0.01	15.56	28.61	13.44	5.52	35.54	0.96	0.36
1969	0.00	0.00	19.45	44.90	12.58	4.78	17.41	0.57	0.30
1980	0.00	0.00	7.03	60.70	6.56	7.10	18.34	0.01	0.31

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.00	-0.01	3.90	16.29	-0.85	-0.74	-18.13	-0.39	-0.06
1969-1980	0.00	0.00	-12.42	15.80	-6.03	2.32	0.93	-0.56	0.01
1948-1980	0.00	-0.01	-8.53	32.09	-6.88	1.58	-17.21	-0.95	-0.05

TOTAL LAND AREA IN HECTARES FOR 1948 = 14671.2

TOTAL LAND AREA IN HECTARES FOR 1969 = 14671.3

TOTAL LAND IN HECTARES FOR 1980 = 14678.3

TOTAL CLASSIFIED ACREAGE FOR 1948 = 14671.3

TOTAL CLASSIFIED ACREAGE FOR 1969 = 14671.2

TOTAL CLASSIFIED ACREAGE FOR 1980 = 14678.3

SUB-WATERSHED 6

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	4.4	0.0	2768.8	6744.6	3510.4	1802.7	12453.2	131.4	34.7
1969	0.0	0.0	4424.9	8664.3	5258.7	2526.6	6469.7	79.4	26.4
1980	0.0	0.0	1749.7	14816.5	1833.7	2433.9	6571.0	3.7	4.2

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-4.4	0.0	1656.1	1919.7	1748.3	723.9	-5983.5	-52.0	-8.3
1969-1980	0.0	0.0	-2675.2	6152.2	-3425.0	-92.7	101.3	-75.7	-22.2
1949-1980	-4.4	0.0	-1019.1	8071.9	-1676.7	631.2	-5882.2	-127.7	-30.5

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	0.00	0.00	59.81	28.46	49.80	40.16	-48.05	-39.57	-23.92
1969-1980	0.00	0.00	-60.46	71.01	-65.13	-3.67	1.57	-95.34	-84.09
1948-1980	0.00	0.00	-36.81	119.68	-47.76	35.01	-47.23	-97.18	-87.90

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.02	0.00	10.09	24.57	12.79	6.57	45.37	0.48	0.13
1969	0.00	0.00	16.12	31.56	19.16	9.20	23.57	0.29	0.10
1980	0.00	0.00	6.37	53.98	6.68	8.87	23.94	0.01	0.02

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-0.02	0.00	6.03	6.99	6.37	2.64	-21.80	-0.19	-0.03
1969-1980	0.00	0.00	-9.75	22.41	-12.48	-0.34	0.37	-0.28	-0.08
1948-1980	-0.02	0.00	-3.71	29.41	-6.11	2.30	-21.43	-0.47	-0.11

TOTAL LAND AREA IN HECTARES FOR 1948 = 27450.1

TOTAL LAND AREA IN HECTARES FOR 1969 = 27450.0

TOTAL LAND IN HECTARES FOR 1980 = 27412.7

TOTAL CLASSIFIED ACREAGE FOR 1948 = 27450.2

TOTAL CLASSIFIED ACREAGE FOR 1969 = 27450.0

TOTAL CLASSIFIED ACREAGE FOR 1980 = 27412.7

SUB-WATERSHED 7

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	74.6	1.6	4128.8	6926.6	1196.7	1380.6	4816.7	181.9	5.1
1969	82.4	0.0	4584.9	9047.1	2445.6	895.0	1537.3	97.6	22.8
1980	112.5	0.0	820.9	12946.6	952.4	2224.9	1649.9	0.0	5.5

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	7.8	-1.6	456.1	2120.5	1248.9	-485.6	-3279.4	-84.3	17.7
1969-1980	30.1	0.0	-3764.0	3899.5	-1493.2	1329.9	112.6	-97.6	-17.3
1949-1980	37.9	-1.6	-3307.9	6020.0	-244.3	844.3	-3166.8	-181.9	0.4

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	10.46	0.00	11.05	30.61	104.36	-35.17	-68.08	-39.57	347.06
1969-1980	36.53	0.00	-82.10	43.10	-61.06	148.59	7.32	-95.34	-75.88
1948-1980	50.80	0.00	-80.12	86.91	-20.41	61.15	-65.75	-97.18	7.84

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.40	0.01	22.06	37.02	6.40	7.38	25.74	0.97	0.03
1969	0.44	0.00	24.50	48.35	13.07	4.78	8.22	0.52	0.12
1980	0.60	0.00	4.39	69.19	5.09	11.89	8.82	0.00	0.03

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	0.04	-0.01	2.44	11.33	6.67	-2.60	-17.52	-0.45	0.09
1969-1980	0.16	0.00	-20.11	20.84	-7.98	7.11	0.60	-0.52	-0.09
1948-1980	0.20	-0.01	-17.68	32.17	-1.31	4.51	-16.92	-0.97	0.00

TOTAL LAND AREA IN HECTARES FOR 1948 = 18712.7

TOTAL LAND AREA IN HECTARES FOR 1969 = 18712.8

TOTAL LAND IN HECTARES FOR 1980 = 18712.7

TOTAL CLASSIFIED ACREAGE FOR 1948 = 18712.6

TOTAL CLASSIFIED ACREAGE FOR 1969 = 18712.7

TOTAL CLASSIFIED ACREAGE FOR 1980 = 18712.7

SUB-WATERSHED 8

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	12.9	0.0	2631.9	5877.7	5274.1	1394.5	6909.0	298.1	284.5
1969	12.2	0.0	3666.6	9328.3	4271.3	1751.7	3346.7	117.5	188.4
1980	0.0	0.0	719.8	14081.3	1824.0	2102.5	3696.6	0.0	252.4

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-0.7	0.0	1034.7	3450.6	-1002.8	357.2	-3562.3	-180.6	-96.1
1969-1980	-12.2	0.0	-2946.8	4753.0	-2447.3	350.8	349.9	-117.5	64.0
1949-1980	-12.9	0.0	-1912.1	8203.6	-3450.1	708.0	-3212.4	-298.1	-32.1

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	10.46	0.00	39.31	58.71	-19.01	25.61	-51.56	-39.57	-33.78
1969-1980	36.53	0.00	-80.37	50.95	-57.30	20.03	10.46	-95.34	33.97
1948-1980	50.80	0.00	-72.65	139.57	-65.42	50.77	-46.50	-97.18	-11.28

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.06	0.00	11.60	25.91	23.25	6.15	30.46	1.31	1.25
1969	0.05	0.00	16.16	41.12	18.83	7.72	14.75	0.52	0.83
1980	0.00	0.00	3.17	62.08	8.04	9.27	16.30	0.00	1.11

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-0.00	0.00	4.56	15.21	-4.42	1.57	-15.70	-0.80	-0.42
1969-1980	-0.05	0.00	-12.99	20.95	-10.79	1.55	1.54	-0.52	0.28
1948-1980	-0.06	0.00	-8.43	36.17	-15.21	3.12	-14.16	-1.31	-0.14

TOTAL LAND AREA IN HECTARES FOR 1948 = 22682.9

TOTAL LAND AREA IN HECTARES FOR 1969 = 22682.9

TOTAL LAND IN HECTARES FOR 1980 = 22676.6

TOTAL CLASSIFIED ACREAGE FOR 1948 = 22682.7

TOTAL CLASSIFIED ACREAGE FOR 1969 = 22682.7

TOTAL CLASSIFIED ACREAGE FOR 1980 = 22676.6

SUB-WATERSHED 9

AREA IN HECTARES

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	131.8	6.6	1934.0	4484.0	3515.7	1247.7	4937.6	59.5	0.0
1969	118.7	0.0	2517.0	7482.4	2423.7	950.2	2777.7	46.3	1.0
1980	97.8	0.0	912.3	9486.0	1348.0	1638.5	2834.7	0.0	0.0

NET CHANGE (HECTARES)

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-13.1	-6.6	583.0	2998.4	-1092.0	-297.5	-2159.9	-13.2	1.0
1969-1980	-20.9	0.0	-1604.7	2003.6	-1075.7	688.3	57.0	-46.3	-1.0
1949-1980	-34.0	-6.6	-1021.7	5002.0	-2167.7	390.8	-2102.9	-59.5	0.0

PERCENT CHANGE

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1949-1969	-9.94	0.00	30.14	66.87	-31.06	-23.84	-43.74	-39.57	-33.78
1969-1980	-17.61	0.00	-63.75	26.78	-44.38	72.44	2.05	-95.34	33.97
1948-1980	-25.80	0.00	-52.83	111.55	-61.66	31.32	-42.59	-97.18	-11.28

% OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948	0.81	0.04	11.85	27.48	21.55	7.65	30.26	0.36	0.00
1969	0.73	0.00	15.43	45.86	14.85	5.82	17.02	0.28	0.01
1980	0.60	0.00	5.59	58.14	8.26	10.04	17.37	0.00	0.00

NETCHANGE AS A % OF TOTAL AREA

	URBAN	WSTLND	SFALLOW	AGRILND	PASTURE	ROUGHGR	WOODS	WETLAND	LAKE
1948-1969	-0.08	-0.04	3.57	18.38	-6.69	-1.82	-13.24	-0.08	0.01
1969-1980	-0.13	0.00	-9.83	12.28	-6.59	4.22	0.35	-0.28	-0.01
1948-1980	-0.21	-0.04	-6.26	30.66	-13.28	2.40	-12.89	-0.36	0.00

TOTAL LAND AREA IN HECTARES FOR 1948 = 16316.9

TOTAL LAND AREA IN HECTARES FOR 1969 = 16316.9

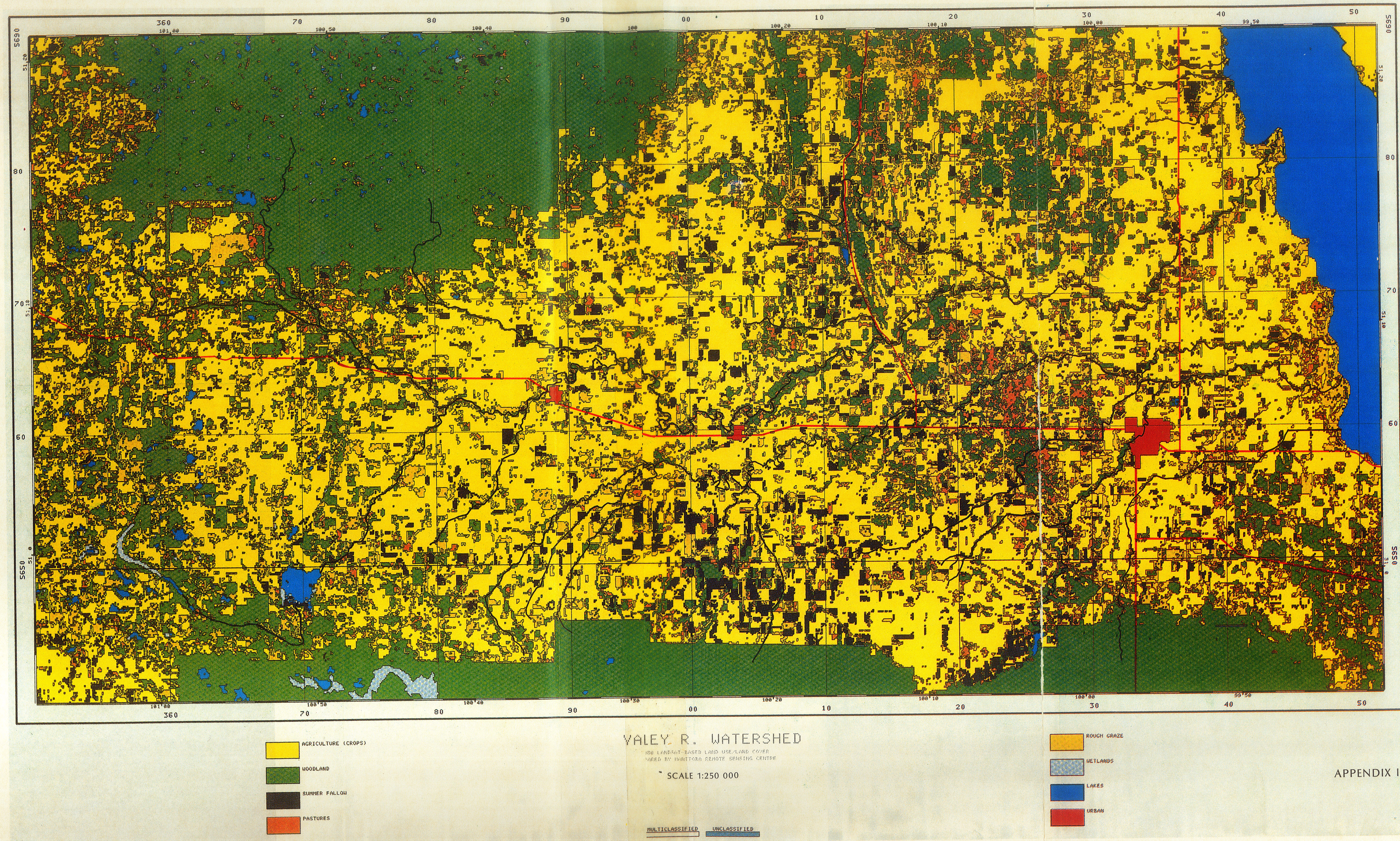
TOTAL LAND IN HECTARES FOR 1980 = 16317.0

TOTAL CLASSIFIED ACREAGE FOR 1948 = 16316.9

TOTAL CLASSIFIED ACREAGE FOR 1969 = 16317.0

TOTAL CLASSIFIED ACREAGE FOR 1980 = 16317.3

STATEMENTS EXECUTED= 2668



VALEY R. WATERSHED
380 LANDSAT-BASED LAND USE/LAND COVER
ARED BY MANITOBA REMOTE SENSING CENTRE
SCALE 1:250 000
AGRICULTURE (CROPS)
WOODLAND
SUMMER FALLOW
PASTURES
ROUGH GRAZE
WETLANDS
LAKES
URBAN
MULTICLASSIFIED
UNCLASSIFIED

APPENDIX II