A Guide to Storage-Yield Analysis at Ungauged River Sites

A. Beersing

Hydrologic Modelling Section
Water Resources Management Division
Department of Environment and Labour
Government of Newfoundland and Labrador

1997

Abstract

Between 1986 and 1994 the Water Resources Management Division of the Newfoundland Department of Environment and Labour conducted seven regional water resources assessments covering the entire Island of Newfoundland. As part of the assessments, regional storage-yield curves were derived for use at ungauged sites. Since the assessments were spread over several years, the regional curves were derived on the basis of different lengths of flow records. It was felt that it was necessary to update the storage-yield curves based on concurrent data up to 1995. As well, several new gauges were installed over the period 1986 and 1994. Inclusion of these new flow records would increase regional representation.

This guide presents the updated non-dimensional storage-yield curves for 66 gauged watersheds. A comparison of these curves with those from the previous assessments shows that the new curves give slightly lower storage requirements for a given yield. There are however, within a specified area, smaller deviations between the updated individual curves than between those of the previous assessments.

A Lotus 1-2-3 spreadsheet was developed to allow a user to select specific gauged watersheds for use as predictors for determining storage-yield curves at ungauged sites. This guide describes the spreadsheet and provides some guidelines on the selection of gauged watersheds. The spreadsheet included in this guide can be used to provide a preliminary estimate of storage requirement for a desired yield at an ungauged site.

Table of Contents

List of Figures

List of Tables

Chapter 1

STORAGE-YIELD APPROACH TO ASSESSMENT OF WATER AVAILABILITY

1.1 Introduction

The effect of man-made instream storage on the naturally variable rate of streamflow must be considered in the assessment of surface water availability for any major use such as municipal water supply and hydro power generation. When site specific streamflow data are available, the historic daily or monthly series of streamflows at the site is obtained. The water supply system is characterized in terms of the demand rate on the storage reservoir. The operation of the system is then simulated on a daily or monthly basis over the period of the streamflow sequence to determine if surpluses or deficits would occur.

When site specific streamflow data are not available, storage-yield curves determined at one or more nearby gauging stations may have to be used. A storage-yield curve gives the relationship between the rate of withdrawal (yield) and the minimum storage capacity required to maintain the required withdrawal rate without interruption of supply. The values for developing the curve are obtained from a simulation of recorded daily or monthly flows as inflows and a given yield on an assumed storage volume. For each yield, the amount of storage required in order to avoid failure is determined. These values are plotted to obtain the storage-yield curve. The curve is usually made dimensionless by expressing the assumed yields as fractions of the mean annual flow from the watershed at the gauging site and expressing the calculated storage volumes as fractions of the mean annual flow volume from the watershed at the gauging site. Similar storage-yield relationships are derived for other nearby gauged watersheds. The results can be combined to produce regional storage-yield curves.

1.2 Objectives of Guide

The objectives of this guide are:

(a) to present the storage-yield curves at all river gauging stations with adequate and up to date flow records on the Island of Newfoundland, thereby updating the storage-yield curves produced as part of seven regional water resources assessments carried out between 1986 and 1994 by the Water Resources Management Division; and

(b) to provide a computer-based procedure for deriving storage-yield curves for use at ungauged river locations.

1.3 Methodology for Determining Storage-Yield Curves

The methodology adopted for determining the updated storage-yield curves consisted of the following steps:

(a) The criteria for selecting river gauging stations to be included for updating were (1) the flow in the river was unregulated; (2) the daily flow data record should be at least 10 years long; and (3) the flow series of the selected rivers should be concurrent over a significant portion of the flow records. The selected period of record was from 1981 to 1995, thus the longest flow series would be 15 years.

(b) Simulations of inflow-demand-storage were done using daily flows. An initial storage volume was assumed. The equation used for water balance was

$$(\text{Surplus/Deficit in Water Supply})_T = (\text{Storage volume})_{T-1} + (\text{River inflow volume})_T - (\text{Demand volume})_T$$

where T was a period of one day.

The *(Demand volume)*$_T$ was assumed to be constant over the entire simulation period. If *(Surplus/Deficit in Water Supply)*$_T$ was a negative value, i.e., a deficit, it indicated a failure of the system and the calculation was re-run with a higher initial storage. If *(Surplus/Deficit in Water Supply)*$_T$ was a positive value, then the surplus was added to the existing storage to be used for simulation during the next time step. However, if the surplus and existing storage exceeded the capacity of the storage reservoir, then the excess became a spill and the storage of the full reservoir was used in the next simulation.

(c) The failure criterion adopted for the analysis was "no failure during the simulated period of record", which for the purposes of this study ranged from 7 to 15 years. The minimum storage volume to satisfy this criterion was then the required storage for the assumed yield. The required storage was expressed as a fraction of the mean annual flow volume. The yield, expressed as a fraction of mean annual flow rate, ranged from 0.05 to 0.95 and increased in steps of 0.05.

(d) Storage yield curves were determined for all selected river gauging stations. These curves were analysed to determine if they were significantly dependent on other watershed or climatic factors, such as, type and area of vegetation cover, area of watershed occupied by lakes and swamps, surficial geology and mean annual precipitation.

(e) The storage-yield curves were grouped together on the basis of the locations of the gauging stations in each of the regions of the Island of Newfoundland as defined as part of previous water resources assessment studies. These updated "regional" curves were then compared to the regional curves determined as part of the previous water resources assessments.

(f) A computer-based procedure was developed to allow users to select appropriate storage-yield curves of gauged watersheds, and average them if necessary, to obtain best estimates of storage requirements at ungauged sites for a desired water yield.

Chapter 2

STORAGE-YIELD RESULTS OF PREVIOUS WATER RESOURCES ASSESSMENTS

2.1 Introduction

From 1986 to 1994, the Water Resources Management Division, with the help of consultants, conducted comprehensive water resources assessments of the Island of Newfoundland. For this purpose, the Island was divided into seven regions as shown in Figure 1. As part of the regional water resources assessments, storage-yield curves were developed for gauged watersheds based on the available flow records. The reader is referred to the following reports [Ref. 1-7] published by the Water Resources Management Division for further details on the analyses:

1. *Regional Water Resources Study of the Eastern Avalon Peninsula (1987)*
2. *Regional Water Resources Study of the Western Avalon Peninsula (1988)*
3. *Regional Water Resources Study of the Bonavista Bay Area (1989)*
4. *Regional Water Resources Study of the Northern Peninsula and Humber Valley (1990)*
5. *Regional Water Resources Study of the Notre Dame Bay Area and Central Newfoundland Region (1991)*
6. *Water Resources Study of the Burin Peninsula and Fortune Bay Area (1993)*
7. *Water Resources Study of Southwestern Newfoundland Region (1994)*

The storage-yield curves for the gauged watersheds within each region were averaged to generate a regional storage-yield curve.

The physiographic, climatic and hydrologic characteristics of each of the seven regions are described briefly in the following sections [Ref. 1-11]. The regional storage-yield curves developed as part of the assessments are summarized at the end of this chapter.

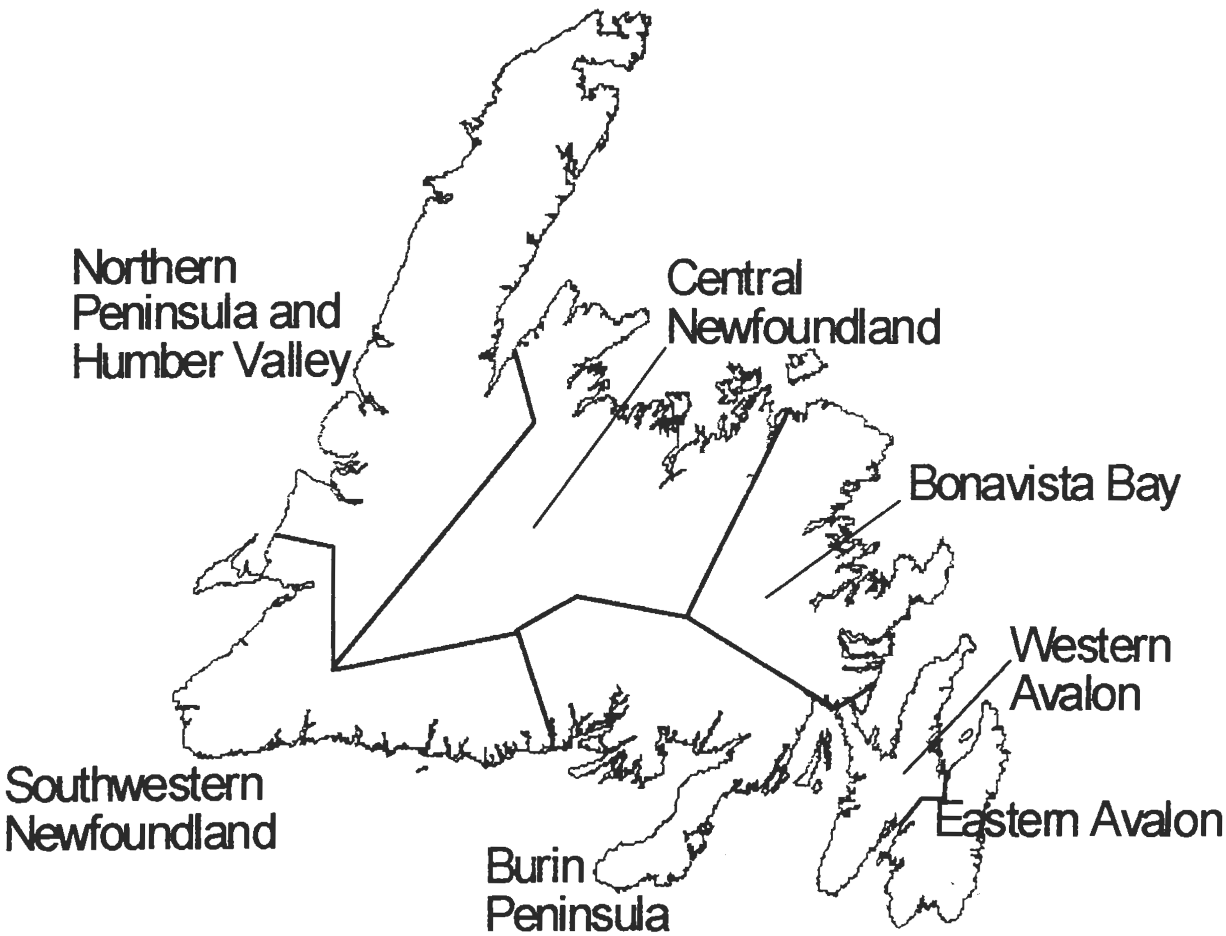


Figure 1 Nominal Boundaries of Regions for Water Resources Assessments

2.2 Description of Regions

2.2.1 Eastern Avalon Peninsula

The Eastern Avalon Peninsula region is the southeastern corner of the Island of Newfoundland. A spine of high hills, with several peaks over 300 m, runs north-south. The coastline is steep in the north, becoming somewhat gentler to the south. The central area is poorly drained and barren, with numerous ponds and bogs. Glaciation has removed much of the overburden, and bedrock is frequently exposed, or close to the surface.

The regional climate is dominated by the ocean environment. The south-flowing cold Labrador current prevents summer temperatures from rising much above 20°C. In the winter, the moderating effect of the ocean generally keeps winter temperatures above -10°C. The warmest month is July and the coldest is February, with mean temperatures at St. John's Airport of 15.5°C and -4.5°C respectively.

The mean annual precipitation along the coast in the region ranges from 1100 mm to 1500 mm, and precipitation is distributed fairly evenly throughout the year. Because of the moderate winter temperatures, winter precipitation can fall as either rain or snow.

This is a region of generally high average runoff, between 1100 and 2000 mm per year. However, because of the very small drainage basins (from less than 1 km^2 to about 250 km^2) and the rough topography, the variation in flow is very rapid. The maximum monthly flows usually occur in April due to a combined effect of snowmelt and precipitation, although a secondary peak is recorded in late fall because of unstable weather conditions after a few snowfalls. The minimums usually occur in late summer to early fall, but winter flows can occasionally be as low as the summer flows after a persistent spell of cold weather.

2.2.2 Western Avalon Peninsula

The western part of the Avalon Peninsula consists of two small peninsulas aligned approximately northeast - southwest and the Isthmus of Avalon. The central parts of each of the two peninsulas are composed of highlands, with peaks over 250 m high. A central lowland lies between the two peninsulas. Much of the region is characterized by barren, irregular and rough topography with numerous rock outcrops. The soil cover is generally thin, and the proximity of bedrock has led to the formation of many bogs and ponds.

The climate is cool, temperate, and wet as expected from the proximity of the area to the North Atlantic Ocean. The cold Labrador current keeps summer temperatures low; the warmest month is August, with a mean August temperature at both Argentia and Colinet of about 15°C. The ocean moderates the climate in the winter, and mean temperatures in February, the coldest month, at Argentia and Colinet are -2°C and - 4°C respectively.

This is a region of generally high average runoff, between 900 and 2000 mm per year. However, because of the very small drainage basins (from less than 1 km^2 to about 250 km^2) and the rough topography, the variation in flow is very rapid. The maximum monthly flows usually occur in April due to a combined effect of snowmelt and precipitation, although a secondary peak is recorded in late fall because of unstable weather conditions after a few snowfalls. The minimums usually occur in late summer to early fall, but winter flows can occasionally be as low as the summer flows, after a persistent spell of cold weather.

2.2.3 Bonavista Bay Area

The Bonavista Bay Area encompasses Swift Current and Sunnyside on the south and extends northwards to Gander Bay. The nominal interior boundary is from Gander Bay to Gander and thence to Swift Current. Several large rivers, notably: Gander, Piper's Hole and Terra Nova flow through the region.

The physiography of the region is characterized by a deeply indented coastline defining several peninsular arms, the most important of which are the Bonavista and Eastport peninsulas. In most locations the land rises rapidly from the coast to a plateau that varies in elevation from about 80 m on the peninsulas to 200 m in the interior of the study area. Glaciers have greatly altered land surface features, reducing relief, modifying drainage patterns and leaving behind a landscape of rounded hills, and plateau areas dotted with a multitude of lakes and swamps (lake surfaces comprise about 7% of the surface area). Boreal forests, mainly of spruce and fir, are supported on a thin mantle of recent soil. Bedrock exposures are common.

The region is exposed to a modified continental type of climate in which extremes of temperature are moderated by proximity to the ocean, especially in coastal areas. In the interior, away from the ocean's influence, the climate exhibits a more continental character with greater variations between winter and summer temperatures. Excepting the southern portion of the area, in the vicinity of Swift Current and Sunnyside, the region is somewhat sheltered from the dominant cyclonic weather systems coming from the west and southwest. On the other hand, the area is directly exposed to weather from the east and the chill of the Labrador current.

There are many small rivers with small or very small drainage areas (a few square kilometres to a few tens of square kilometres), but also a few with drainage areas of several hundred and even above a thousand square kilometres. The average runoff in the region varies mainly between 800 and 1300 mm per year. The maximum monthly flows are recorded in April and May, the higher flow occurring in April in the eastern and lower portion, and in May in the higher and western portion. The minimum monthly flows are recorded in summer.

2.2.4 Notre Dame Bay Area and Central Newfoundland Region

The Notre Dame Bay Area and Central Newfoundland Region has, for the Island of Newfoundland, a relatively continental climate. It is generally flat and well forested.

Because of the general tilting of the central plateau towards the northeast, this region has rivers with large drainage basins in addition to the many smaller ones which is characteristic of the whole island. For example, the Exploits River has a drainage area of over 9,000 km^2.

Mean annual runoff for the region is generally the lowest for the island, ranging from 700 mm to 900 mm per year. The maximum mean monthly flows occur in May, with a secondary peak in November. The minimum mean monthly flows occur in July-August, with a secondary minimum in February.

2.2.5 Humber Valley and Northern Peninsula Region

The Humber Valley and Northern Peninsula region covers all the land drained by the Humber River, all of the Great Northern Peninsula, and a small area around the inner part of White Bay. The Northern Peninsula is dominated by the Long Range Mountains, which reach heights of over 600 m. The Humber Valley area, by contrast, consists largely of a northeast-southwest trough, in which lie Deer Lake and Grand Lake. The coastal area is mountainous, with numerous fjords. The mountains throughout the region result in an orographic effect on precipitation. The land rises rapidly from the coast, and there is a decrease in precipitation on the leeward side of the mountains. This region, with the exception of the Humber River, has only small and average size basins of up to a few hundred square kilometres.

The climate of the Island of Newfoundland is modified continental, the extremes of a continental climate being tempered by the ocean. The moderating effect decreases with distance inland. The Humber Valley part of the region has a climate similar to the rest of the Island. Corner Brook, for example, has temperatures close to those in Gander, with the overall average being slightly higher. Corner Brook is slightly more continental than coastal locations in the south and east, having slightly cooler winters and slightly warmer summers than St. John's, for example, by a degree or two on the average. Communities on the Northern Peninsula, however, experience lower temperatures year round, with the effect increasing with latitude. The mean annual temperature in the St. Anthony/Roddickton area is around 2°C, compared with about 3°C in Daniel's Harbour and about 5°C in Corner Brook.

The average runoff is variable according to topography, but generally is very high, varying mainly between 900 and 1800 mm per year. The maximum mean monthly flows occur as a rule in May. Although secondary peaks in the fall are occasionally recorded, these are much less significant than in other regions, especially those on the eastern side of the island. The minimum mean monthly flows are observed in February, with a secondary low in July.

2.2.6 Southwestern Newfoundland Region

The Southwestern Newfoundland region covers the west coast of Newfoundland south of Corner Brook and Bay of Islands, and the entire south coast west of McCallum. Most of the area lies in uninhabited uplands, including the Long Range Mountains and the Annieopsquatch Mountains. These uplands consist predominantly of exposed bedrock, bog and tundra vegetation. The river valleys are steep. East of the divide of the Long Range Mountains the land is completely barren; the northwest facing side is wooded.

The climate in the southern part of the region is characterized by relatively mild winters with varying amounts of snowfall and cool summers. Winter thaws occasionally occur, and the driest periods tend to be in the summer. The west coast of the region has slightly warmer summers than the south coast with a heavier winter snowfall. The average annual precipitation on the coast is more than 1,500 mm/year. The area is directly exposed to the dominant cyclonic weather systems coming from the southwest.

The average runoff is variable according to topography, but generally is the highest on the island, varying between 1300 and 2000 mm per year. Because of the rugged topography in those basins which have no significant natural storage (especially in the southern portion of the region), the maximum runoff per unit area is relatively higher than in the other regions.

2.2.7 Burin Peninsula and Fortune Bay Region

The Burin Peninsula and Fortune Bay covers all of the Burin Peninsula, up to and including Piper's Hole River. It extends to the west to include all the land draining into the northern part of Fortune Bay, as well as the Connaigre Peninsula.

The Burin Peninsula is characterized by relatively low relief with numerous small ponds and brooks. The drainage pattern was originally developed by the erosion of valleys along the lines of weakness produced by tectonic folding and faulting. This pattern has been extensively modified by glaciation. A thin layer of surficial sediment with sparse vegetation overlies bedrock. Much of the region is barren and bog covered. Forested areas are rare. The north part of Fortune Bay and the Bay d'Espoir area have a similar geologic history and are similarly barren. Much of this region is a plateau with elevations ranging from 200 - 300 m, behind steep coastal cliffs.

The climate on the Burin Peninsula and coastal areas is characterized by mild winters and cool summers. Winter thaws are frequent, and the driest periods tend to be in the summer (e.g., August). The interior areas, particularly the upper reaches of the Bay d'Espoir basin, are slightly drier, with colder winters. The area is directly exposed to the dominant cyclonic weather systems coming from the southwest.

This is a region of generally high average runoff, between 1000 and 1700 mm per year. However, because of the very small drainage basins (from less than 1 km^2 to about 300 km^2) and the rough topography, the variation in flow is very rapid. The maximum monthly flows usually occur in April due to a combined effect of snowmelt and precipitation, although a secondary peak is recorded in late fall because of unstable weather conditions after a few snowfalls. The minimums usually occur in late summer to early fall.

2.3 Summary of Regional Storage-Yield Curves

As part of the water resources assessment studies, detailed analyses were carried out for all rivers gauged in the region at the time of the studies assuming that they were being used for water supply. Each of the gauged basins was analysed assuming various live storage volumes. For each volume of storage, the operation of the storage reservoir was simulated for several withdrawal rates. For each withdrawal rate, the amount of storage required in order to avoid failure was determined. The results were then combined to produce a regional storage-yield curve. This curve gives an estimate of the constant rate at which water can be withdrawn without shortages. Table 1 gives selected numerical values of the seven regional curves.

Table 1 Numerical Values of Regional Storage-Yield Curves from Previous Studies

Regions	**EA**	**WA**	**BN**	**CN**	**NP**	**SW**	**BU**
# of Stations	4	8	8	9	7	7	4
End-Year	85	86	87	89	88	92	91
Yield Fractions			**Storage Fractions**				
0.2	0.025	0.025	0.043	0.044	0.075	0.025	0.050
0.4	0.075	0.075	0.107	0.113	0.200	0.100	0.100
0.6	0.200	0.150	0.183	0.185	0.400	0.250	0.200
0.8	0.300	0.300	0.350	0.331	0.500	0.500	0.300

EA: **Eastern Avalon**
WA: **Western Avalon**
BN: **Bonavista Bay**
CN: **Central Nfld.**
NP: **Northern Peninsula & Humber Valley**
SW: **Southwestern Nfld.**
BU: **Burin Peninsula**

Chapter 3

UPDATED STORAGE-YIELD CURVES

3.1 Database

The database used for determining the storage-yield curves consisted of daily flow records at 66 gauged watersheds on the island. Table 2 lists the watersheds together with their pertinent physiographic characteristics and the length of flow record used in the analysis at each gauge. All flow records end in 1995. Of the 66 gauges, 29 had 15 years of daily flow records, while only 7 stations had less than 10 years of daily flow records. Notwithstanding the "record length" criterion of at least 10 years stated in Section 1.3(a), the 7 stations with less than 10 years of record were included to increase regional representation. The flow records satisfy the criterion for concurrent period of record. This provides a consistent period for storage-yield analyses since non-concurrent periods of record can significantly skew the shape of the storage-yield curves.

3.2 Analysis and Results

The methodology described in Section 1.3(b) and 1.3(c) was applied to each of the 66 flow records. The storage-yield results for each gauged watershed are given in Table 3. Table 3 also provides the mean annual runoff at each gauging station as calculated over the selected period of record. Figure 2 shows the isolines of mean annual runoff based on the values given in Table 3.

Table 2 Characteristics of Gauged Watersheds Included in Storage–Yield Analysis

GAUGE NUMBER	NAME	UTM EAST	UTM NORTH	#YRs	AREA (km2)	Fraction FOREST	Fraction SWAMP	Fraction LAKE	Fraction BARREN	Fraction ACLS
02YA001	Ste. Genevieve River near Forresters Point	514537	5665010	15	306.0	0.64	0.14	0.22	0.00	0.96
02YA002	Bartletts River near St. Anthony	594372	5700432	10	33.6	0.40	0.03	0.13	0.44	0.99
02YC001	Torrent River at Bristol's Pool	489307	5605971	15	624.0	0.33	0.04	0.13	0.50	0.99
02YD002	Northeast Brook near Roddickton	562392	5642074	15	200.0	0.83	0.04	0.13	0.00	0.99
02YE001	Greavett Brook above Portland Creek Pond	458630	5556393	12	95.7	0.49	0.06	0.06	0.39	0.88
02YG001	Main River at Paradise Pool	488728	5517608	10	627.0	0.78	0.06	0.07	0.09	0.63
02YG002	Middle Arm Brook below Flatwater Pond	547312	5517062	9	224.0					
02YH001	Bottom Creek near Rocky Harbour	434262	5492669	10	33.4	0.79	0.02	0.11	0.08	0.93
02YJ001	Harrys River below Highway Bridge	399435	5380921	15	640.0	0.79	0.09	0.06	0.07	0.75
02YJ003	Pinchgut Brook at outlet of Pinchgut Lake	425429	5406150	10	119.0	0.86	0.05	0.05	0.04	1.00
02YK002	Lewaseechjeech Brook at Little Grand Lake	431217	5385663	14	470.0	0.55	0.06	0.10	0.29	1.00
02YK005	Sheffield Brook near Trans–Canada Highway	524298	5464686	15	391.0	0.68	0.08	0.10	0.15	0.94
02YK007	Glide Brook below Glide Lake	473059	5439963	12	112.0	0.87	0.09	0.04	0.00	0.98
02YK008	Boot Brook at Trans–Canada Highway	492442	5456856	10	20.4	0.75	0.22	0.02	0.01	0.65
02YL001	Upper Humber River Near Reidville	473613	5454042	15	2110.0	0.74	0.06	0.05	0.15	0.75
02YL004	South Brook at Pasedena	455169	5428746	13	58.5	0.94	0.01	0.01	0.05	0.08
02YL005	Rattler Brook near McIvers	419252	5434433	11	17.0	0.91	0.08	0.02	0.00	0.46
02YL008	Upper Humber River above Black Brook	478751	5496112	8	471.0					
02YM003	South West Brook near Baie Verte	555826	5526873	15	93.2	0.91	0.07	0.05	0.00	0.56
02YN002	Lloyds River Below King George IV Lake	438519	5343335	15	469.0	0.23	0.06	0.12	0.63	1.00
02YN003	Star Brook below Star Lake	483179	5380512	8	427.0					
02YO006	Peters River near Botwood	616011	5440218	15	177.0	0.83	0.13	0.03	0.02	0.97
02YO007	Leech Brook near Grand Falls	585795	5421784	12	88.3	0.70	0.24	0.04	0.02	0.73
02YO008	Great Rattling Brook above Tote River Confluence	607852	5409071	12	823.0	0.73	0.19	0.05	0.03	0.55
02YO010	Junction Brook near Badger	571537	5424702	11	61.6	0.81	0.09	0.10	0.00	0.89
02YO012	Southwest Brook at Lewisporte	641788	5453086	7	47.7	0.80	0.08	0.12	0.00	0.67
02YP001	Shoal Arm Brook near Badger Bay	586231	5469233	14	63.8	0.88	0.07	0.06	0.00	0.79
02YQ001	Gander River at Big Chute	656944	5431155	15	4400.0	0.76	0.08	0.09	0.07	0.91
02YQ004	Northwest Gander River near Gander Lake	641002	5403291	13	2150.0	0.66	0.25	0.06	0.03	0.44
02YQ005	Salmon River near Glenwood	652285	5430592	9	80.8	0.85	0.11	0.04	0.00	0.87
02YR001	Middle Brook near Gambo	703787	5409584	15	275.0	0.75	0.07	0.18	0.01	0.98
02YR002	Ragged Harbour River near Musgrave Harbour	709929	5474958	15	399.0	0.68	0.16	0.17	0.00	0.96
02YR003	Indian Bay Brook near Northwest Arm	727770	5436364	15	554.0	0.70	0.13	0.20	0.00	0.97

ACLS : Area Controlled by Lakes and Swamps   UTM: Locations of Gauges   #YRs: No. of years of flow data

Table 2 (Cont.) Characteristics of Gauged Watersheds Included in Storage–Yield Analysis

GAUGE NUMBER	NAME	UTM EAST	UTM NORTH	#YRs	AREA (km2)	Fraction FOREST	Fraction SWAMP	Fraction LAKE	Fraction BARREN	Fraction ACLS
02YS003	Southwest Brook at Terra Nova National Park	722577	5387946	15	36.7	0.84	0.14	0.02	0.00	1.00
02YS005	Terra Nova River at Glovertown	719574	5393950	11	2000.0					
02ZA001	Little Barachois Brook near St. George's	396569	5366550	15	343.0	0.60	0.02	0.07	0.30	0.83
02ZA002	Highlands River at Trans Canada Highway	367168	5329755	14	72.0	0.82	0.01	0.04	0.13	0.43
02ZA003	Little Codroy River near Doyles	335741	5298623	14	139.0	0.66	0.07	0.04	0.16	0.73
02ZB001	Isle Aux Morts River below Highway Bridge	349008	5275124	15	205.0	0.08	0.06	0.07	0.78	0.60
02ZC002	Grandy Brook below Top Pond Brook	445145	5300504	14	230.0	0.20	0.01	0.05	0.82	0.34
02ZD002	Grey River near Grey River	504894	5287526	12	1340.0					
02ZE004	Conne River at outlet of Conne River Pond	612769	5335965	6	99.5	0.60	0.34	0.05	0.01	1.00
02ZF001	Bay Du Nord River at Big Falls	616815	5289101	15	1170.0	0.32	0.05	0.18	0.44	0.96
02ZG001	Garnish River near Garnish	626521	5230069	15	205.0	0.26	0.01	0.09	0.63	0.96
02ZG002	Tides Brook below Freshwater Pond	631594	5220544	15	166.0	0.37	0.04	0.09	0.49	0.92
02ZG003	Salmonier River near Lamaline	593161	5191750	15	115.0	0.16	0.06	0.07	0.73	0.92
02ZG004	Rattle Brook Near Boat Harbour	661701	5257246	15	42.7	0.34	0.03	0.14	0.46	0.92
02ZG005	Little Barasway Brook near Molliers	604659	5216981	9	28.2	0.31	0.08	0.07	0.55	0.50
02ZH001	Pipers Hole River at Mothers Brook	702692	5313751	15	764.0	0.11	0.48	0.18	0.23	0.91
02ZH002	Come By Chance River near Goobies	727891	5311540	15	43.3	0.40	0.02	0.08	0.50	0.92
02ZJ001	Southern Bay River near Southern Bay	746077	5363532	15	67.4	0.82	0.06	0.10	0.03	0.86
02ZJ002	Salmon Cove River near Champneys	773748	5366689	13	73.6	0.74	0.06	0.13	0.07	0.82
02ZJ003	Shoal Harbour River near Clarenville	719936	5343290	10	106.0	0.65	0.10	0.07	0.18	0.68
02ZK001	Rocky River near Colinet	759795	5235633	15	285.0	0.51	0.02	0.10	0.37	0.55
02ZK002	Northeast River near Placentia	738945	5240224	15	89.6	0.48	0.16	0.15	0.24	0.81
02ZK003	Little Barachois River near Placentia	724209	5229352	13	37.2	0.86	0.11	0.02	0.01	0.34
02ZK004	Little Salmonier River near North Harbour	747788	5223552	13	104.0	0.23	0.38	0.08	0.31	0.91
02ZK005	Trout Brook near Bellevue	743166	5277346	10	50.3	0.36	0.00	0.07	0.57	0.50
02ZL003	Spout Cove Brook near Spout Cove	787911	5302345	15	10.8	0.42	0.01	0.08	0.49	1.00
02ZL004	Shearstown Brook at Shearstown	777601	5276441	13	28.9	0.70	0.00	0.04	0.27	0.39
02ZL005	Big Brook at Lead Cove	791909	5328261	14	11.2	0.39	0.03	0.07	0.51	1.00
02ZM006	Northeast Pond River at Northeast Pond	812693	5283915	15	3.6	0.75	0.17	0.04	0.04	1.00
02ZM009	Seal Cove Brook near Cappahayden	806931	5195841	15	53.6	0.38	0.01	0.12	0.51	1.00
02ZM016	South (Mahers) River near Holyrood	793185	5252420	13	17.3	0.22	0.05	0.06	0.68	0.90
02ZN001	Northwest Brook at Northwest Pond	781832	5195162	14	53.3	0.09	0.00	0.13	0.79	1.00
02ZN002	St. Shotts River near Trepassey	768294	5178582	11	15.5	0.88	0.00	0.12	0.00	0.82

ACLS : Area Controlled by Lakes and Swamps UTM: Locations of Gauges #YRs: No. of years of flow data

Table 3 Updated Storage-Yield Curves for Gauged Watersheds

WCSNO	AREA	REC	MAR	0.01	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
02YA001	306.0	81	848	0.000	0.000	0.000	0.000	0.001	0.005	0.010	0.037	0.068	0.100	0.134	0.168	0.202	0.237	0.272	0.309	0.350	0.433	0.515	0.646
02YA002	33.6	86	1420	0.000	0.004	0.017	0.032	0.051	0.070	0.090	0.110	0.139	0.178	0.216	0.258	0.294	0.333	0.372	0.411	0.450	0.536	0.726	0.916
02YC001	624.0	81	1176	0.000	0.000	0.010	0.025	0.042	0.060	0.079	0.098	0.118	0.137	0.158	0.178	0.198	0.236	0.275	0.314	0.353	0.393	0.479	0.566
02YD002	200.0	81	823	0.000	0.003	0.011	0.023	0.057	0.094	0.132	0.169	0.207	0.245	0.283	0.322	0.360	0.399	0.437	0.476	0.515	0.554	0.592	0.696
02YE001	95.7	84	1527	0.000	0.002	0.009	0.020	0.031	0.044	0.059	0.074	0.090	0.106	0.124	0.141	0.159	0.181	0.219	0.256	0.294	0.332	0.476	0.661
02YG001	627.0	86	1415	0.000	0.000	0.002	0.007	0.019	0.036	0.056	0.075	0.095	0.115	0.135	0.156	0.176	0.208	0.248	0.287	0.327	0.366	0.447	0.537
02YG002	224.0	87	844	0.000	0.006	0.017	0.029	0.042	0.057	0.074	0.094	0.113	0.134	0.162	0.203	0.244	0.285	0.337	0.426	0.516	0.605	0.695	0.785
02YH001	33.4	86	749	0.000	0.000	0.001	0.006	0.012	0.019	0.027	0.035	0.044	0.057	0.072	0.091	0.121	0.158	0.196	0.233	0.271	0.312	0.400	0.490
02YJ001	640.0	81	1306	0.000	0.000	0.001	0.003	0.007	0.011	0.017	0.025	0.035	0.046	0.076	0.114	0.151	0.189	0.227	0.294	0.383	0.478	0.616	0.780
02YJ003	119.0	86	1059	0.000	0.001	0.004	0.009	0.016	0.023	0.032	0.042	0.053	0.064	0.094	0.133	0.171	0.210	0.249	0.289	0.329	0.374	0.457	0.552
02YK002	470.0	82	1238	0.000	0.000	0.003	0.009	0.017	0.027	0.042	0.058	0.075	0.092	0.109	0.127	0.144	0.177	0.216	0.255	0.294	0.344	0.478	0.647
02YK005	391.0	81	834	0.000	0.000	0.004	0.010	0.020	0.032	0.045	0.059	0.074	0.090	0.106	0.123	0.156	0.195	0.233	0.298	0.383	0.468	0.553	0.665
02YK007	112.0	84	751	0.000	0.003	0.009	0.019	0.033	0.049	0.066	0.084	0.102	0.120	0.138	0.159	0.189	0.229	0.285	0.374	0.463	0.553	0.724	1.014
02YK008	20.4	86	791	0.001	0.003	0.014	0.027	0.041	0.056	0.072	0.090	0.109	0.127	0.146	0.164	0.184	0.212	0.268	0.344	0.433	0.521	0.663	0.879
02YL001	2110.0	81	1178	0.000	0.000	0.004	0.010	0.024	0.038	0.054	0.071	0.099	0.137	0.176	0.215	0.253	0.292	0.331	0.371	0.410	0.449	0.489	0.742
02YL004	58.5	83	988	0.000	0.000	0.001	0.004	0.012	0.022	0.033	0.046	0.063	0.088	0.115	0.143	0.172	0.201	0.232	0.271	0.328	0.416	0.527	0.779
02YL005	17.0	85	985	0.000	0.004	0.012	0.021	0.033	0.047	0.060	0.083	0.120	0.158	0.196	0.234	0.272	0.311	0.349	0.394	0.438	0.482	0.536	0.632
02YL008	471.0	88	1769	0.000	0.000	0.004	0.010	0.022	0.041	0.060	0.079	0.099	0.118	0.138	0.158	0.178	0.198	0.219	0.240	0.265	0.306	0.396	0.485
02YM003	93.2	81	835	0.001	0.007	0.017	0.028	0.043	0.058	0.085	0.123	0.162	0.200	0.239	0.277	0.316	0.394	0.485	0.575	0.673	0.811	0.959	1.250
02YN002	469.0	81	1416	0.000	0.000	0.001	0.003	0.010	0.018	0.028	0.042	0.056	0.070	0.085	0.113	0.157	0.202	0.247	0.291	0.336	0.382	0.427	0.532
02YN003	427.0	88	1057	0.000	0.000	0.000	0.002	0.004	0.010	0.019	0.032	0.046	0.060	0.075	0.090	0.105	0.121	0.140	0.178	0.216	0.256	0.301	0.420
02YO006	177.0	81	808	0.000	0.002	0.009	0.021	0.035	0.044	0.066	0.084	0.105	0.125	0.146	0.182	0.221	0.259	0.298	0.361	0.451	0.633	0.923	1.213
02YO007	88.3	84	831	0.001	0.007	0.016	0.026	0.036	0.052	0.070	0.089	0.107	0.126	0.145	0.164	0.192	0.232	0.272	0.316	0.405	0.527	0.796	1.084
02YO008	823.0	84	822	0.000	0.006	0.016	0.026	0.040	0.055	0.072	0.090	0.108	0.125	0.144	0.164	0.186	0.208	0.235	0.306	0.396	0.486	0.577	0.760
02YO010	61.6	85	720	0.000	0.006	0.017	0.031	0.046	0.063	0.080	0.097	0.115	0.133	0.151	0.169	0.197	0.236	0.274	0.313	0.351	0.390	0.450	0.651
02YO012	47.7	89	831	0.000	0.001	0.006	0.014	0.023	0.034	0.048	0.062	0.076	0.110	0.152	0.194	0.237	0.280	0.324	0.367	0.410	0.454	0.498	0.544
02YP001	63.8	82	927	0.000	0.003	0.011	0.020	0.029	0.039	0.052	0.068	0.101	0.140	0.180	0.220	0.260	0.301	0.343	0.384	0.426	0.572	0.757	1.009
02YQ001	4400.0	81	870	0.000	0.001	0.008	0.019	0.031	0.045	0.062	0.081	0.101	0.122	0.142	0.163	0.185	0.207	0.245	0.283	0.346	0.432	0.654	0.929
02YQ004	2150.0	83	866	0.000	0.005	0.015	0.025	0.038	0.055	0.073	0.091	0.109	0.127	0.148	0.169	0.191	0.213	0.235	0.258	0.309	0.397	0.630	0.906
02YQ005	80.8	87	917	0.001	0.007	0.015	0.025	0.037	0.051	0.070	0.090	0.112	0.133	0.154	0.176	0.198	0.224	0.267	0.357	0.447	0.538	0.628	0.718
02YR001	275.0	81	750	0.000	0.002	0.012	0.025	0.040	0.056	0.073	0.091	0.110	0.129	0.148	0.168	0.187	0.215	0.299	0.384	0.469	0.554	0.771	1.058
02YR002	399.0	81	752	0.000	0.009	0.025	0.043	0.063	0.083	0.104	0.125	0.147	0.169	0.191	0.220	0.262	0.305	0.385	0.472	0.560	0.760	1.048	1.336
02YR003	554.0	81	756	0.000	0.002	0.014	0.029	0.045	0.063	0.081	0.101	0.122	0.143	0.165	0.189	0.214	0.239	0.292	0.378	0.464	0.550	0.805	1.093

AREA: Drainage Area in km2　　REC: Start Year of Flow Record Used for Analysis, End Year is 1995 in all cases.

MAR: Mean Annual Runoff in mm

Top Row is "Yield" as a Fraction of Mean Annual Flow. "Storage" values given in table are as Fractions of Mean Annual Volumes.

Table 3 (Cont.) Updated Storage-Yield Curves for Gauged Watersheds

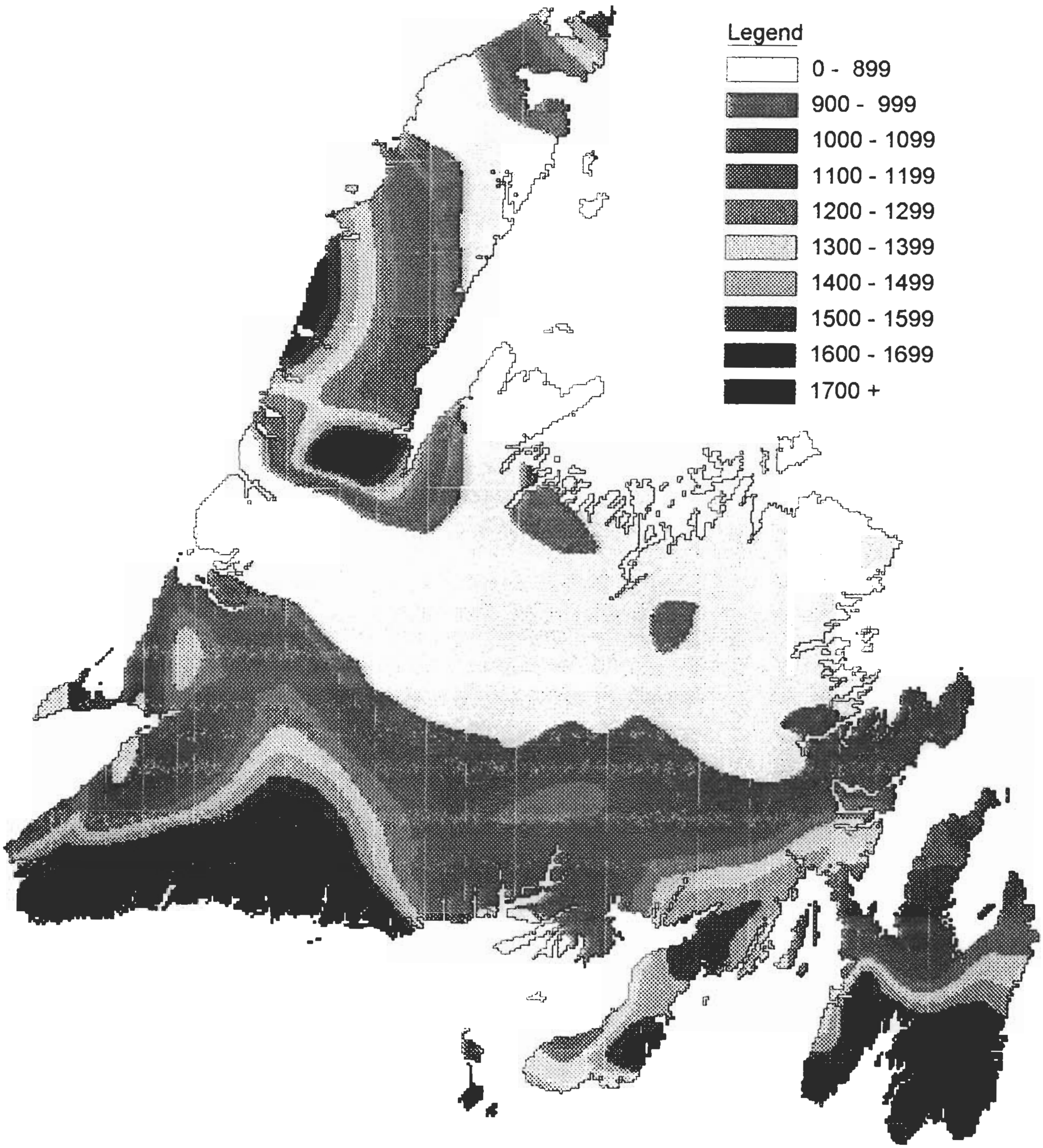
WCSNO	AREA	REC	MAR	0.01	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.85	0.90	0.95
02YS003	36.7	81	875	0.000	0.001	0.005	0.010	0.016	0.031	0.045	0.066	0.090	0.116	0.142	0.185	0.228	0.272	0.327	0.413	0.500	0.590	0.680	0.873
02YS005	2000.0	85	775	0.000	0.000	0.001	0.008	0.017	0.029	0.044	0.060	0.077	0.096	0.115	0.136	0.157	0.189	0.232	0.275	0.351	0.436	0.522	0.687
02ZA001	343.0	81	1022	0.000	0.000	0.001	0.008	0.018	0.030	0.047	0.064	0.082	0.099	0.117	0.135	0.173	0.211	0.249	0.287	0.325	0.364	0.430	0.596
02ZA002	72.0	82	1177	0.000	0.000	0.003	0.008	0.015	0.022	0.029	0.039	0.064	0.102	0.141	0.185	0.229	0.273	0.317	0.362	0.408	0.454	0.500	0.626
02ZA003	139.0	82	1752	0.000	0.000	0.003	0.007	0.011	0.015	0.025	0.038	0.053	0.067	0.094	0.134	0.177	0.221	0.264	0.308	0.352	0.398	0.443	0.603
02ZB001	205.0	81	2058	0.000	0.001	0.005	0.009	0.017	0.028	0.042	0.056	0.071	0.085	0.100	0.114	0.143	0.183	0.229	0.274	0.319	0.368	0.462	0.677
02ZC002	230.0	82	1978	0.000	0.002	0.004	0.009	0.015	0.022	0.031	0.046	0.061	0.076	0.091	0.106	0.121	0.138	0.181	0.225	0.269	0.313	0.368	0.554
02ZD002	1340.0	84	1279	0.000	0.002	0.008	0.017	0.029	0.043	0.058	0.075	0.093	0.111	0.129	0.147	0.165	0.183	0.219	0.259	0.299	0.339	0.380	0.446
02ZE004	99.5	90	1166	0.000	0.000	0.002	0.005	0.013	0.024	0.035	0.047	0.059	0.071	0.083	0.095	0.108	0.124	0.140	0.157	0.184	0.224	0.265	0.306
02ZF001	1170.0	81	1114	0.000	0.001	0.007	0.016	0.026	0.037	0.049	0.063	0.079	0.097	0.115	0.135	0.155	0.176	0.197	0.219	0.240	0.296	0.455	0.725
02ZG001	205.0	81	1439	0.000	0.002	0.007	0.014	0.024	0.035	0.046	0.061	0.075	0.091	0.106	0.122	0.138	0.156	0.175	0.194	0.212	0.238	0.275	0.415
02ZG002	166.0	81	1559	0.000	0.000	0.005	0.013	0.022	0.032	0.044	0.055	0.070	0.086	0.104	0.122	0.140	0.159	0.178	0.197	0.216	0.236	0.289	0.450
02ZG003	115.0	81	1346	0.000	0.004	0.013	0.024	0.036	0.048	0.063	0.079	0.095	0.112	0.129	0.146	0.163	0.195	0.245	0.311	0.376	0.441	0.517	0.719
02ZG004	42.7	81	1570	0.000	0.003	0.008	0.016	0.027	0.038	0.049	0.062	0.074	0.088	0.101	0.116	0.133	0.152	0.170	0.189	0.208	0.241	0.302	0.377
02ZG005	28.2	87	1222	0.000	0.002	0.011	0.022	0.033	0.044	0.056	0.069	0.084	0.100	0.117	0.138	0.159	0.180	0.201	0.225	0.250	0.289	0.392	0.524
02ZH001	764.0	81	1073	0.000	0.004	0.013	0.024	0.036	0.049	0.063	0.081	0.099	0.119	0.140	0.161	0.183	0.204	0.226	0.266	0.352	0.438	0.524	0.728
02ZH002	43.3	81	1386	0.000	0.004	0.011	0.018	0.028	0.039	0.051	0.063	0.075	0.090	0.107	0.123	0.139	0.157	0.178	0.214	0.251	0.289	0.365	0.445
02ZJ001	67.4	81	1002	0.000	0.007	0.017	0.029	0.044	0.063	0.084	0.105	0.128	0.153	0.179	0.205	0.231	0.266	0.302	0.342	0.420	0.552	0.796	1.078
02ZJ002	73.6	83	1077	0.000	0.004	0.013	0.024	0.037	0.051	0.067	0.084	0.101	0.118	0.136	0.154	0.174	0.208	0.247	0.287	0.326	0.400	0.498	0.783
02ZJ003	106.0	86	965	0.000	0.003	0.011	0.020	0.030	0.042	0.055	0.070	0.088	0.107	0.128	0.150	0.172	0.195	0.229	0.280	0.359	0.445	0.532	0.619
02ZK001	301.0	81	1197	0.000	0.001	0.003	0.010	0.021	0.033	0.046	0.062	0.078	0.094	0.110	0.126	0.145	0.164	0.186	0.207	0.230	0.267	0.305	0.432
02ZK002	89.6	81	1550	0.000	0.000	0.004	0.013	0.024	0.036	0.052	0.068	0.084	0.100	0.117	0.136	0.154	0.173	0.192	0.214	0.236	0.259	0.324	0.399
02ZK003	37.2	83	1424	0.000	0.000	0.000	0.002	0.008	0.020	0.032	0.044	0.057	0.076	0.095	0.114	0.134	0.153	0.172	0.193	0.217	0.252	0.290	0.376
02ZK004	104.0	83	1712	0.000	0.001	0.003	0.010	0.019	0.031	0.046	0.062	0.079	0.096	0.115	0.134	0.153	0.173	0.195	0.217	0.251	0.288	0.328	0.427
02ZK005	50.3	86	980	0.000	0.000	0.003	0.006	0.011	0.020	0.032	0.043	0.055	0.068	0.085	0.101	0.118	0.135	0.151	0.170	0.202	0.262	0.347	0.506
02ZL003	10.8	81	1184	0.000	0.001	0.004	0.009	0.017	0.030	0.045	0.062	0.082	0.103	0.126	0.152	0.179	0.212	0.260	0.344	0.428	0.545	0.725	0.908
02ZL004	28.9	83	967	0.000	0.000	0.004	0.013	0.024	0.037	0.049	0.064	0.080	0.099	0.120	0.141	0.162	0.183	0.205	0.226	0.247	0.269	0.301	0.368
02ZL005	11.2	82	1145	0.000	0.001	0.007	0.016	0.027	0.039	0.051	0.066	0.082	0.097	0.113	0.129	0.147	0.168	0.189	0.216	0.243	0.273	0.309	0.387
02ZM006	3.6	81	1197	0.000	0.000	0.004	0.014	0.030	0.046	0.062	0.078	0.100	0.123	0.146	0.169	0.194	0.219	0.244	0.279	0.317	0.366	0.549	0.834
02ZM009	53.6	81	1733	0.000	0.000	0.005	0.013	0.023	0.035	0.048	0.061	0.075	0.089	0.102	0.116	0.133	0.151	0.173	0.196	0.218	0.242	0.283	0.499
02ZM016	17.3	83	1348	0.000	0.000	0.001	0.006	0.017	0.029	0.042	0.058	0.073	0.089	0.106	0.122	0.140	0.160	0.181	0.219	0.256	0.294	0.332	0.370
02ZN001	53.3	82	1863	0.000	0.000	0.003	0.012	0.023	0.037	0.051	0.066	0.083	0.101	0.120	0.138	0.157	0.175	0.197	0.218	0.240	0.262	0.284	0.306
02ZN002	15.5	85	1678	0.000	0.000	0.002	0.008	0.017	0.027	0.036	0.048	0.060	0.078	0.096	0.115	0.134	0.152	0.171	0.193	0.216	0.246	0.286	0.362

AREA: Drainage Area in km2 REC: Start Year of Flow Record Used for Analysis, End Year is 1995 in all cases.

MAR: Mean Annual Runoff in mm

Top Row is "Yield" as a Fraction of Mean Annual Flow. "Storage" values given in table are as Fractions of Mean Annual Volumes.

Mean Annual Runoff (1995)



3.3 Discussion of Results

Figures 3(a) to 3(i) show the updated storage-yield curves grouped by locational proximity. Appendix A shows the results in Table 3 and Figures 3(a) to 3(i) as storage isolines for selected yield requirements. These maps were derived from the individual storage-yield curves to provide an indication of spatial variability. The figures and maps indicate that for a given yield the storage requirement generally tends to be highest in central Newfoundland and the Northern Peninsula and lowest on the Avalon Peninsula. These differences are due to regional hydrological differences. More specifically, as described in Section 2.2, watersheds on the Northern Peninsula and in central areas tend to have their annual hydrographs dominated by a single snowmelt event in the spring, while on the east coast runoff is relatively more evenly distributed. From a water yield perspective, and all other factors being equal, a more even distribution of runoff tends to lower storage requirements.

The figures also indicate that, although there may be significant differences between storage-yield curves because of regional hydrological differences, the non-dimensional curves when grouped according to locational proximity are comparable to one another. Differences between the individual storage-yield curves for a given group can be partially attributed to a number of factors such as drainage area, fraction of drainage area covered by lakes and swamps, regional mean annual runoff, among others. Making the storage-yield curves non-dimensional by taking yield as fraction of mean annual flow and storage as fraction of mean annual volume reduces the effects of these factors to some degree. However, as the results of the updated storage-yield analysis show, differences between individual storage-yield curves still occur. This suggests that care must be exercised in the selection of storage-yield curves for use as predictors for ungauged sites when there are several gauged watersheds close to the target watershed.

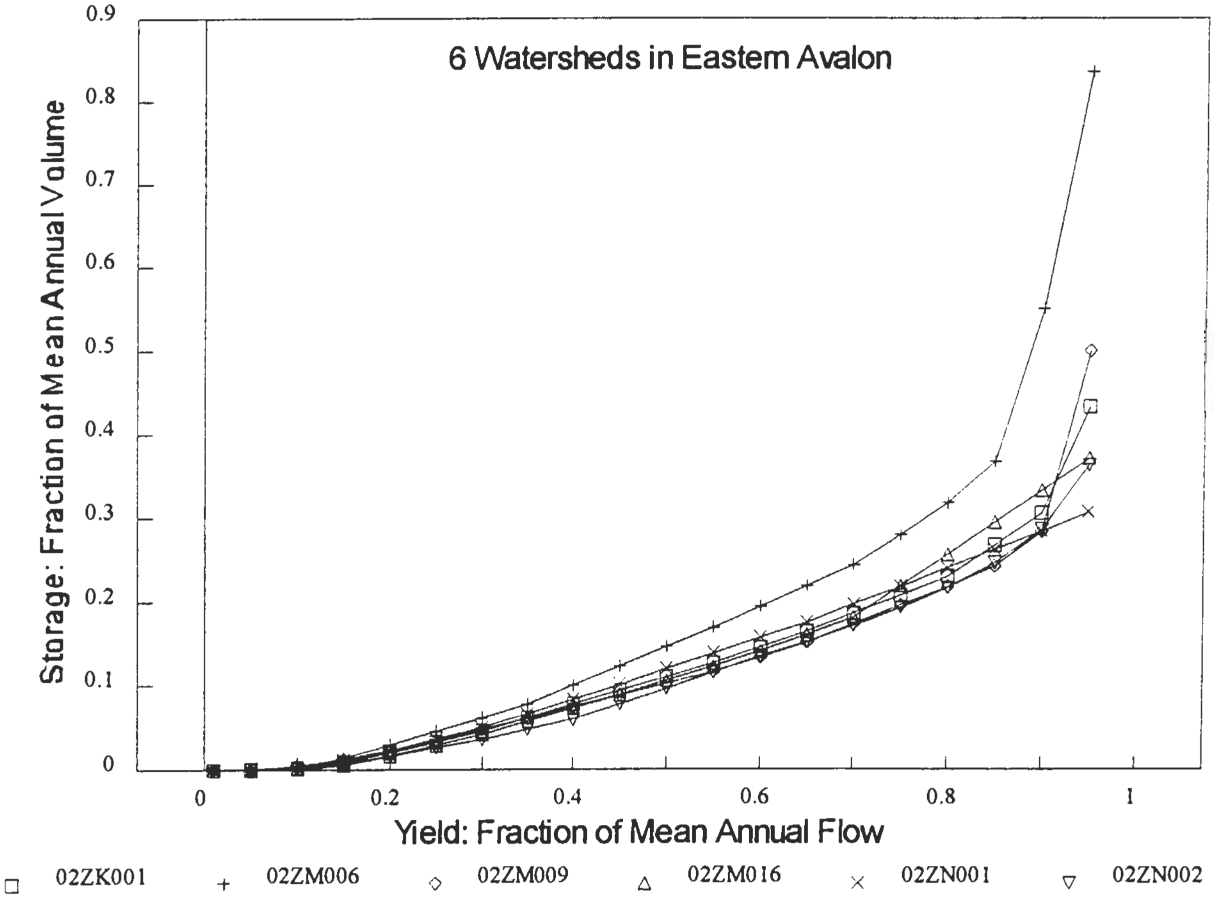


Figure 3(a) Storage-Yield Curves at Gauges Grouped by Locational Proximity

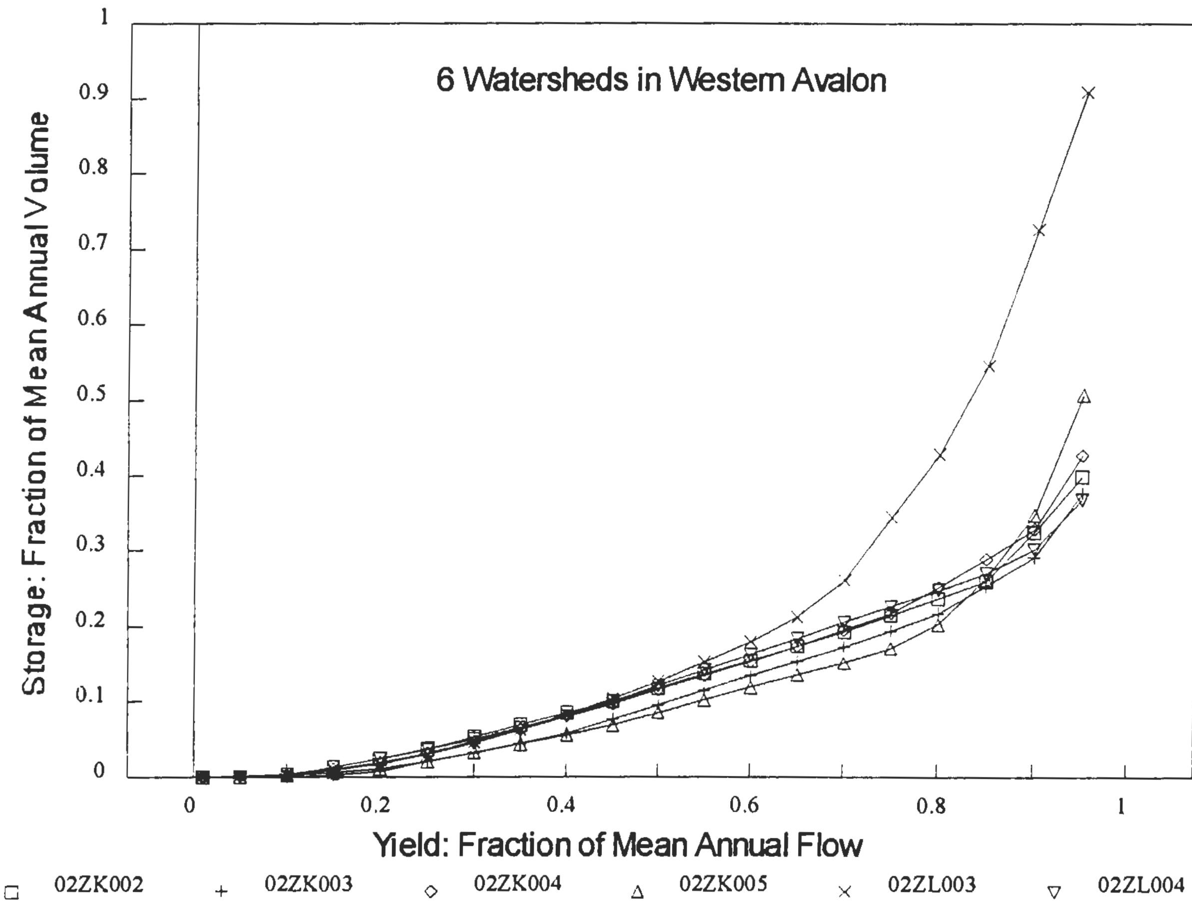


Figure 3(b) Storage-Yield Curves at Gauges Grouped by Locational Proximity

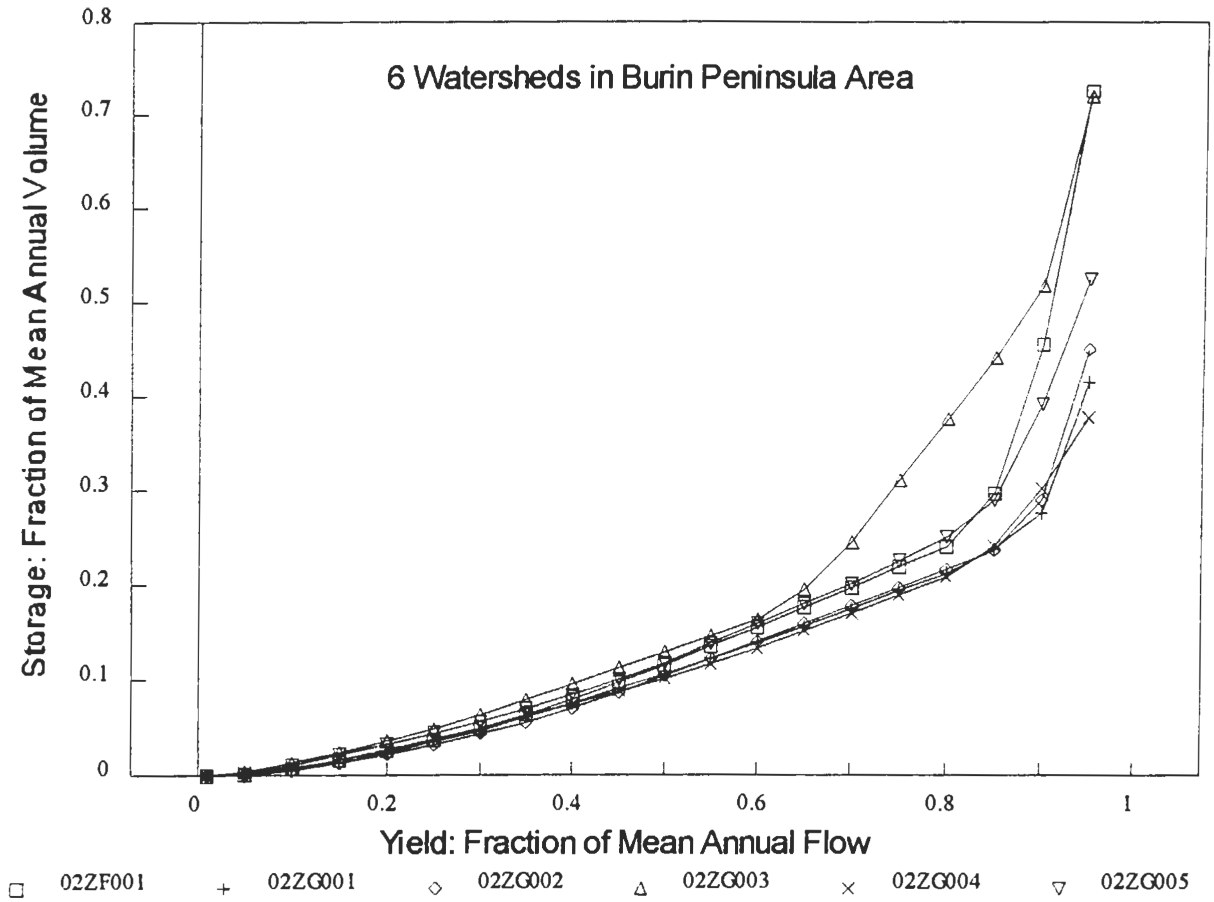


Figure 3(c) Storage-Yield Curves at Gauges Grouped by Locational Proximity

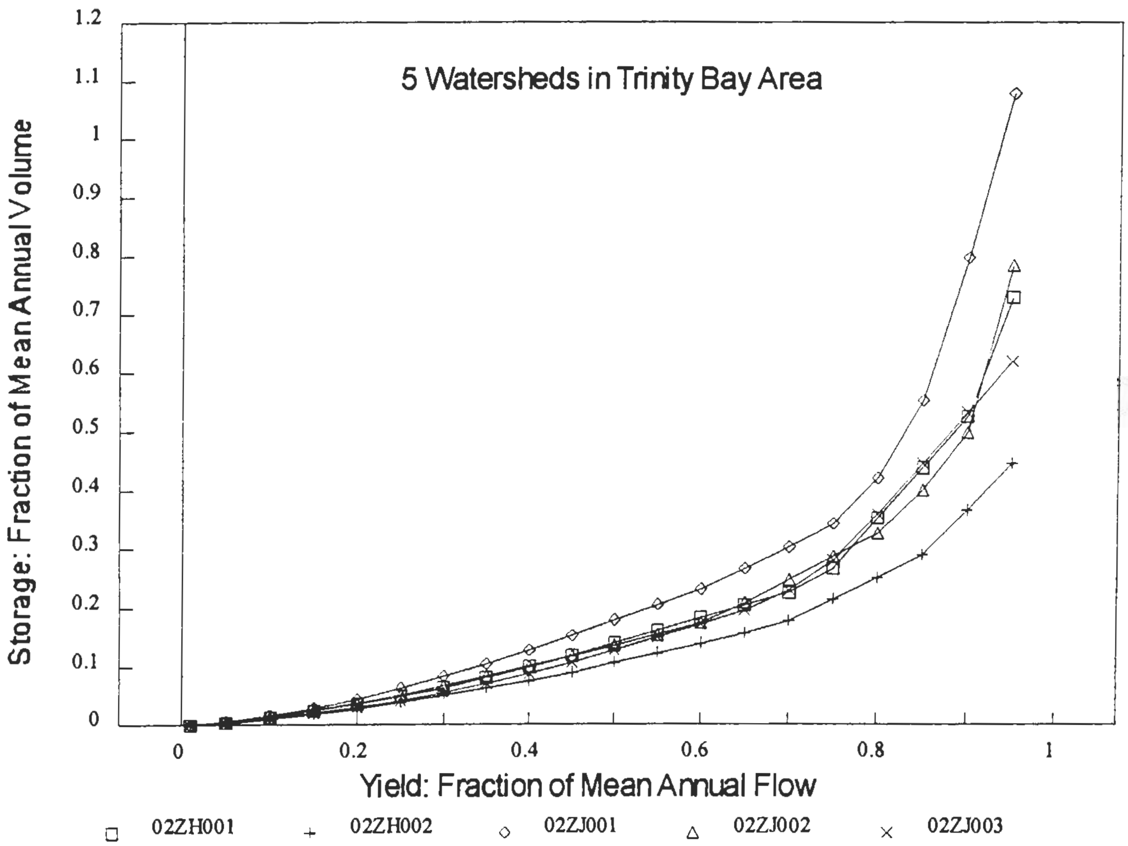


Figure 3(d) Storage-Yield Curves at Gauges Grouped by Locational Proximity

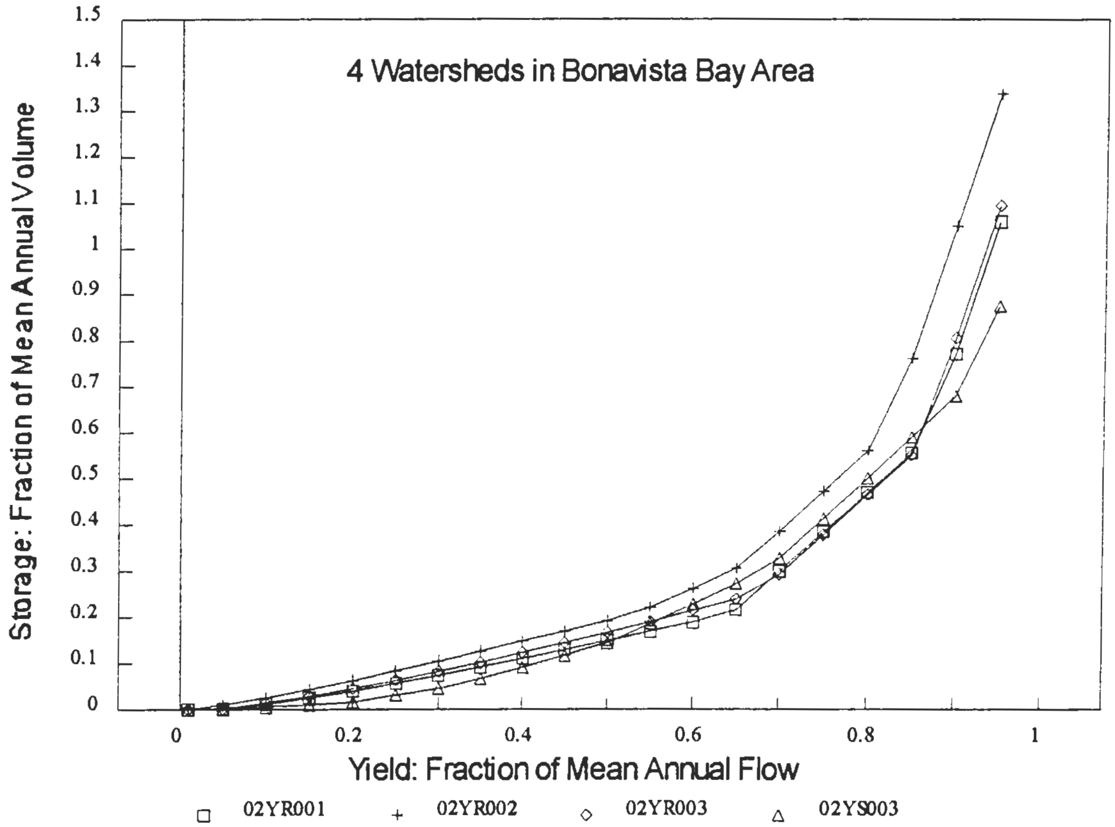


Figure 3(e) Storage-Yield Curves at Gauges Grouped by Locational Proximity

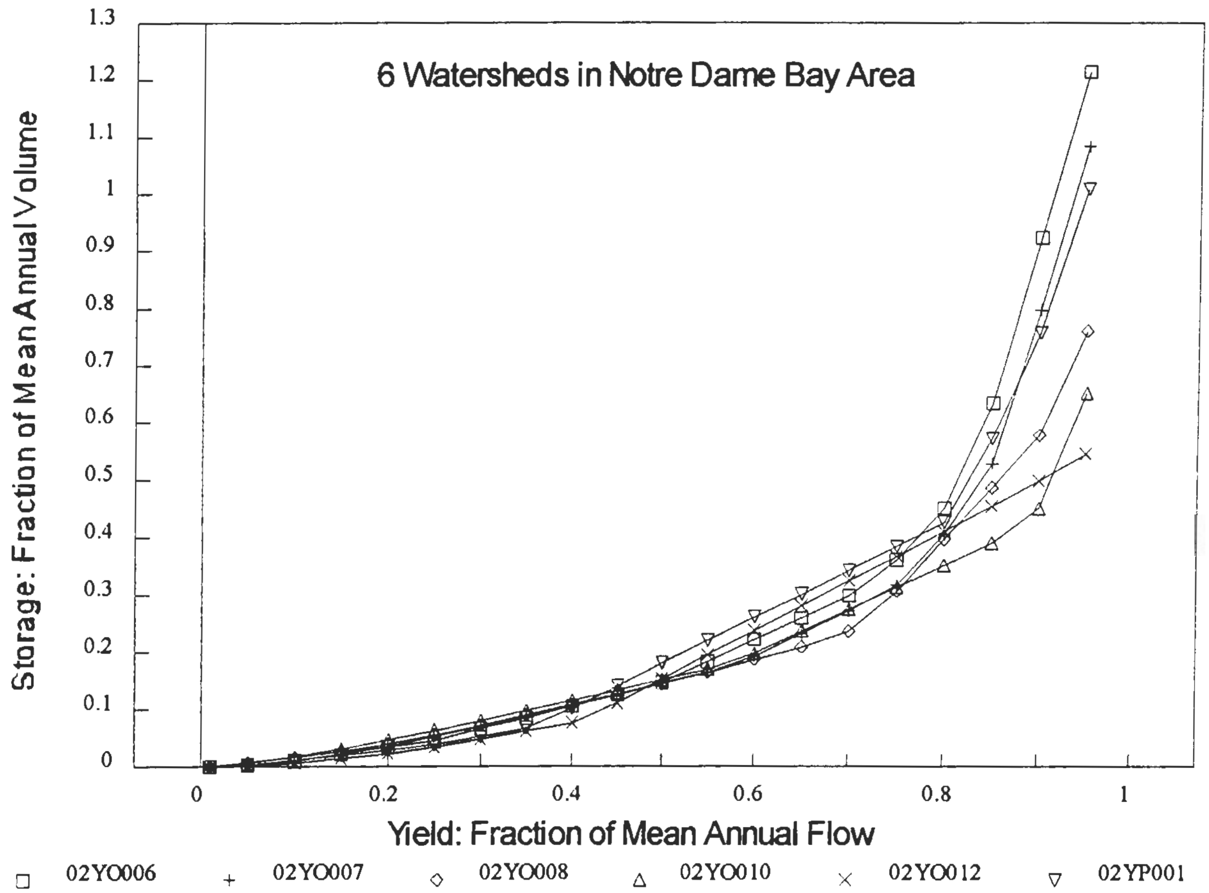


Figure 3(f) Storage-Yield Curves at Gauges Grouped by Locational Proximity

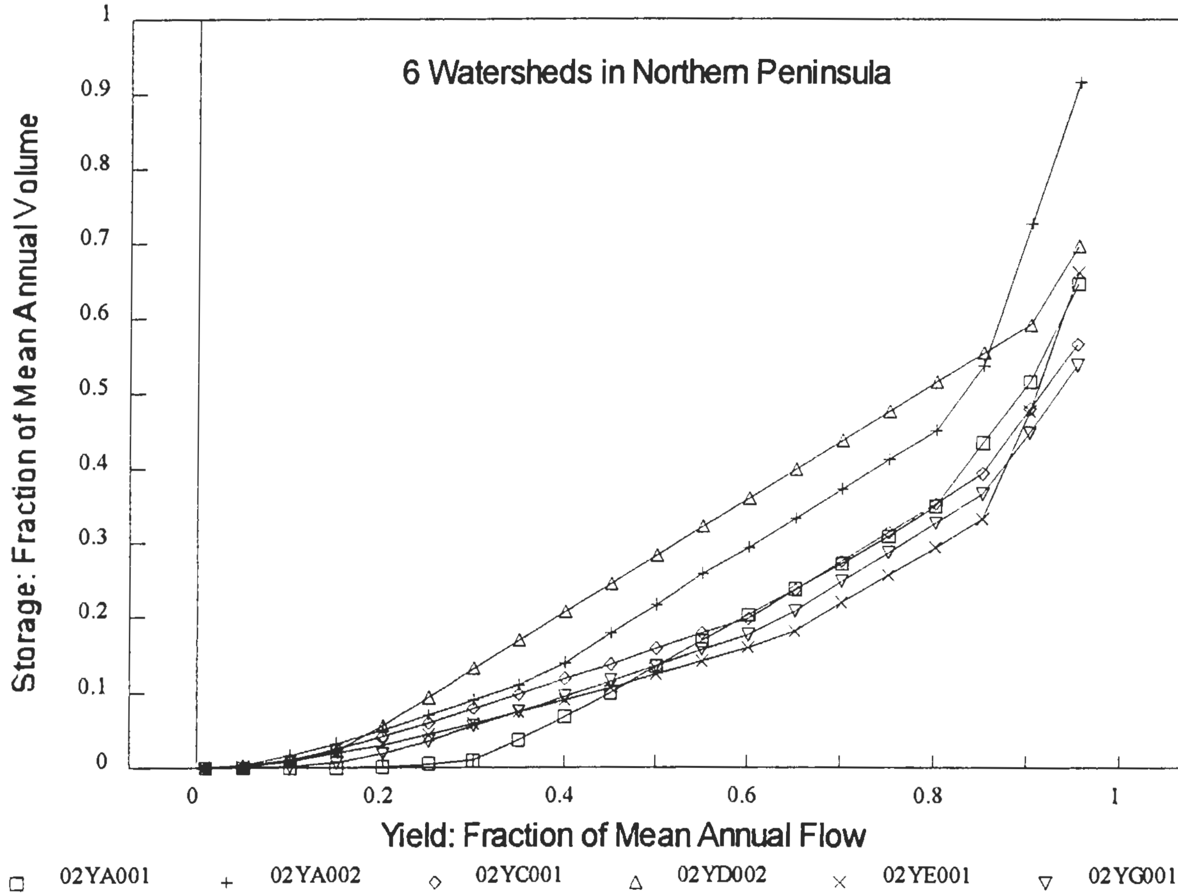


Figure 3(g) Storage-Yield Curves at Gauges Grouped by Locational Proximity

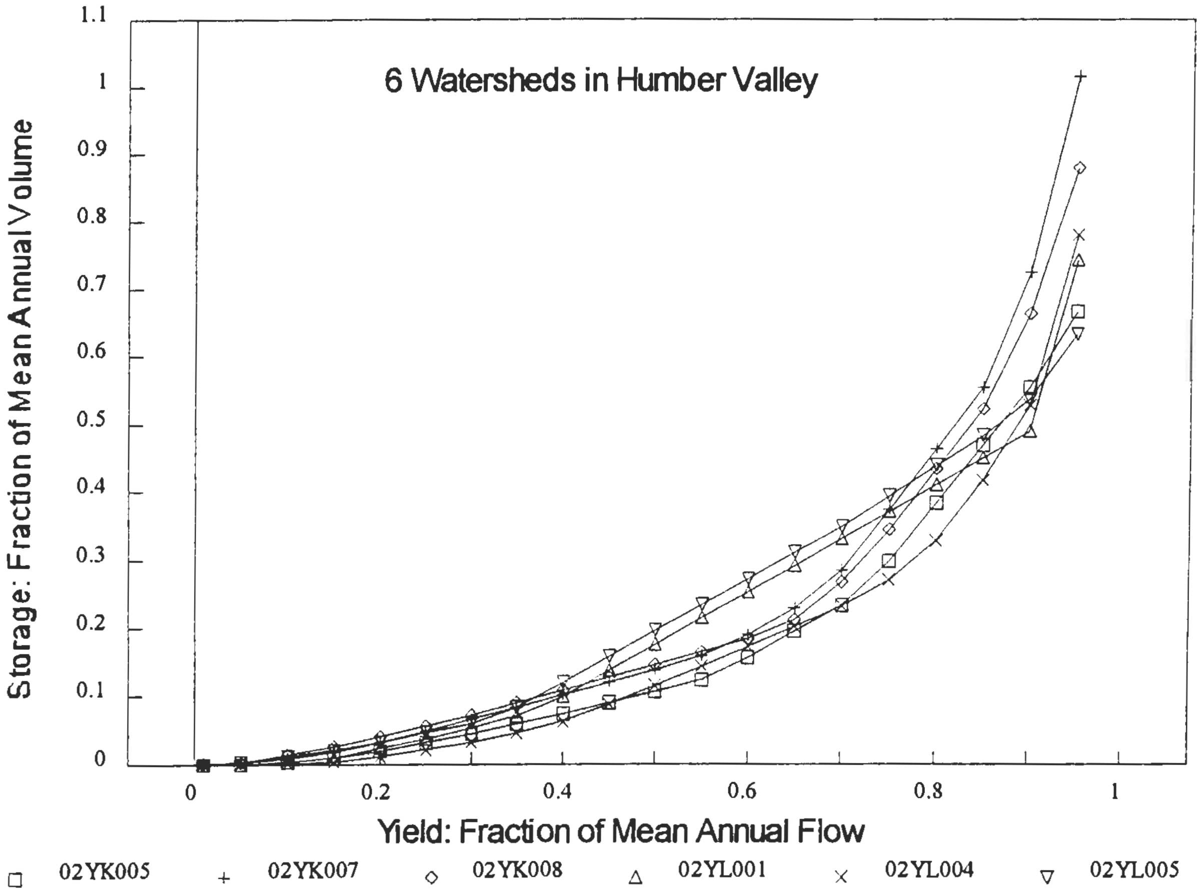


Figure 3(h) Storage-Yield Curves at Gauges Grouped by Locational Proximity

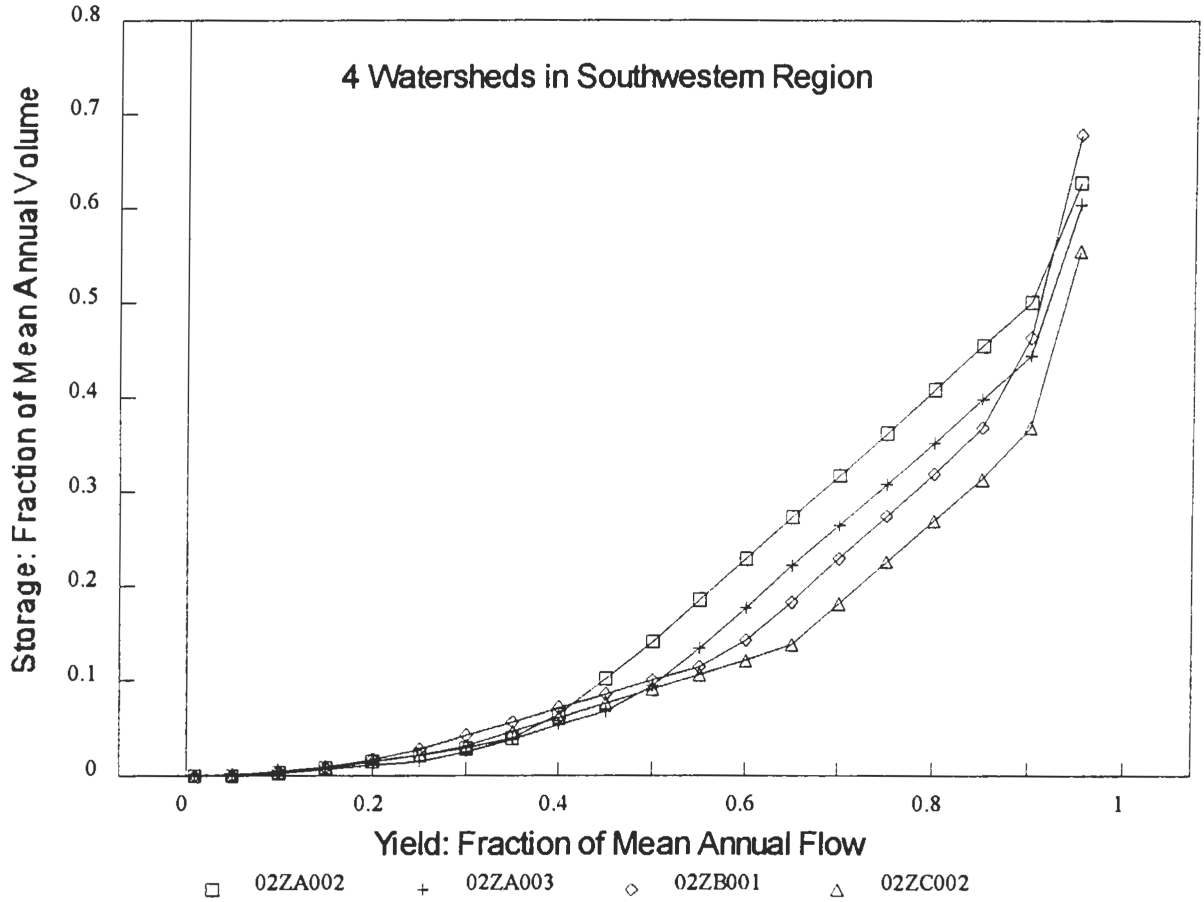


Figure 3(i) Storage-Yield Curves at Gauges Grouped by Locational Proximity

3.4 Comparison of Updated Regional Curves With Previous Studies

The curves presented in Table 3 were grouped according to regions as delineated in Figure 1. The regions represent the nominal boundaries of previous water resources assessment studies. The values were averaged and are presented in Table 4 for each region. For comparison, the corresponding values from the previous studies are also presented (in parentheses) in Table 4.

Table 4 Comparison of Regional Storage-Yield Curves: Updated Curves and Curves from Previous Studies (*numbers in parentheses*)

Regions	EA	WA	BN	CN	NP	SW	BU
# of Stations	8	6	10	11	16	9	7
End-Year	95	95	95	95	95	95	95
Yield Fractions				**Storage Fractions**			
0.2	0.019	0.022	0.026	0.036	0.026	0.015	0.026
	(0.025)	(0.025)	(0.043)	(0.044)	(0.075)	(0.025)	(0.050)
0.4	0.075	0.078	0.077	0.110	0.095	0.066	0.077
	(0.075)	(0.075)	(0.107)	(0.113)	(0.200)	(0.100)	(0.100)
0.6	0.149	0.151	0.142	0.221	0.199	0.162	0.142
	(0.200)	(0.150)	(0.183)	(0.185)	(0.400)	(0.250)	(0.200)
0.8	0.257	0.246	0.241	0.430	0.364	0.332	0.241
	(0.300)	(0.300)	(0.350)	(0.331)	(0.500)	(0.500)	(0.300)

EA: **Eastern Avalon**
WA: **Western Avalon**
BN: **Bonavista Bay**
CN: **Central Nfld.**
NP: **Northern Peninsula & Humber Valley**
SW: **Southwestern Nfld.**
BU: **Burin Peninsula**

The results indicate that while most of the values from the previous assessments and the present study were comparable, those of the Northern Peninsula Region (NP which includes the Humber Valley) and Southwestern Newfoundland Region (SW) were significantly lower when using the updated curves. These were two regions for which the divergences between the individual storage-yield curves were significant in the previous water resources assessments (see Ref. 4 and 7). The NP region, in particular, showed the highest divergence presumably because of the extensive area (of varying topography and hydrology) covered by the nominal boundaries of the region. The divergences were also significant between the updated storage-yield curves when the NP Region was divided into two areas (see Figures 3(g) and 3(h)). It can be concluded that the differences between the previous and updated values are a reflection of this divergence. This suggests that, although grouping storage-yield curves by region reduces the differences between the curves, estimates of storage requirements at ungauged sites should be calculated from records at gauges which as close as possible to the target site. It may be preferable to select storage-yield curves to be used as predictors based on locational proximity and physiographic similarity. It can be reasonably assumed that watersheds which are close to one another and which are physiographically similar to one another will in all likelihood have similar storage-yield curves.

3.5 Computer-Based Approach to Estimating Storage Requirements at Ungauged Sites

Although, as was done in the previous water resource assessments, there is some advantage to grouping and averaging the individual curves within regions for estimating storage requirements at ungauged sites, it may be better to allow some flexibility in the choice of gauges depending upon the exact location of the target site. This approach however requires a computer-based methodology to be effective.

A Lotus 1-2-3[1] spreadsheet is provided with this guide to facilitate the calculation of storage requirements at ungauged sites. Figures 4(a) and 4(b) show the spreadsheet as it appears on the computer screen. Figure 4(a) is for a hypothetical watershed in the Northern Peninsula and Figure 4(b) is for a hypothetical watershed on the Esatern Avalon Peninsula. Shaded cells are cells where data input is required. The procedure for obtaining the storage requirement at a given ungauged site is as follows:

[1] On the 1st line, *Cell E3*, the user enters the name of the watershed for reference.

[2] On the 2nd line, *Cell I4*, the user enters the drainage area in km^2 of the watershed at the site where the reservoir is to be located.

[3] On the 3rd line, *Cell I5*, the user enters the required yield in m^3/s. This yield may include a flow rate which may be required as part of a fish habitat maintenance agreement.

---

[1] Registered Trademark of Lotus Development Corporation

Estimation of Live Storage Requirements for Desired Yield

Enter Name of Watershed	A Watershed on the Northern Peninsula							
Enter Drainage Area of Watershed (km2)							55.60	
Enter Desired Yield (YR, m3/s)							0.53	
Enter Index of Max. of 5 Rep. Gauged Watersheds-SEE INDEX MAP								
If No. of Gauges Selected less than 5, Enter 0 in Cell----------------							--------------|	
	DA km2	F.Forest	F.Lakes	F.ACLS	MAR	SF		
02YC001	624.0	0.33	0.13	0.99	1176	0.046	3	User selects the closest and/or
NA	NA	NA	NA	NA	NA	NA	0	most representative gauged watersheds
02YE001	95.7	0.49	0.06	0.88	1527	0.034	5	whose indices are shown on an index map provided.
02YG001	627.0	0.78	0.07	0.63	1415	0.022	6	
NA	NA	NA	NA	NA	NA	NA	0	
IF MAR of Watershed User-specified, Enter 1, Else 0							0	User has the option of specifying MAR.
The Value in Next Cell is Ignored							1200	
MAR Based on Mean MAR of Selected Watersheds							1373	
Mean Annual Flow (MAF) for Watershed (m3/s)							2.42	
Yield Fraction, YF=YR/MAF, If YR < 0.05, YR Set to 0.05							0.22	
Average (Based on Selected Gauges) Storage Fraction, SF							0.034	Based on selected gauges, Spreadsheet
Required Minimum Live Storage (SR, m3)===========>							2,580,000	calculates Storage Requirement, rounded to nearest 10,000 m3.

Shaded box: Cells where data are entered.

Figure 4a Layout of Spreadsheet for Calculation of Storage Requirements at Ungauged Sites

Estimation of Live Storage Requirements for Desired Yield

Enter Name of Watershed		A Watershed on the Eastern Avalon Peninsula						
Enter Drainage Area of Watershed (km2)							55.60	
Enter Desired Yield (YR, m3/s)							0.53	
Enter Index of Max. of 5 Rep. Gauged Watersheds–SEE INDEX MAP								
If No. of Gauges Selected less than 5, Enter 0 in Cell---------------							--------------|	
	DA km2	F.Forest	F.Lakes	F.ACLS	MAR	SF		
02ZM009	53.6	0.38	0.12	1.00	1733	0.017	63	User selects the closest and/or
NA	NA	NA	NA	NA	NA	NA	0	most representative gauged watersheds
02ZN001	53.3	0.09	0.13	1.00	1863	0.016	65	whose indices are shown on an index map provided.
02ZN002	15.5	0.88	0.12	0.82	1678	0.012	66	
NA	NA	NA	NA	NA	NA	NA	0	
IF MAR of Watershed User–specified, Enter 1, Else 0							0	User has the option of specifying MAR.
The Value in Next Cell is Ignored							1200	
MAR Based on Mean MAR of Selected Watersheds							1758	
Mean Annual Flow (MAF) for Watershed (m3/s)							3.10	
Yield Fraction, YF=YR/MAF, If YR < 0.05, YR Set to 0.05							0.17	
Average (Based on Selected Gauges) Storage Fraction, SF							0.015	Based on selected gauges, Spreadsheet
Required Minimum Live Storage (SR, m3)===========>							1,470,000	calculates Storage Requirement, rounded to nearest 10,000 m3.

[shaded box] Cells where data are entered.

Figure 4b   Layout of Spreadsheet for Calculation of Storage Requirements at Ungauged Sites

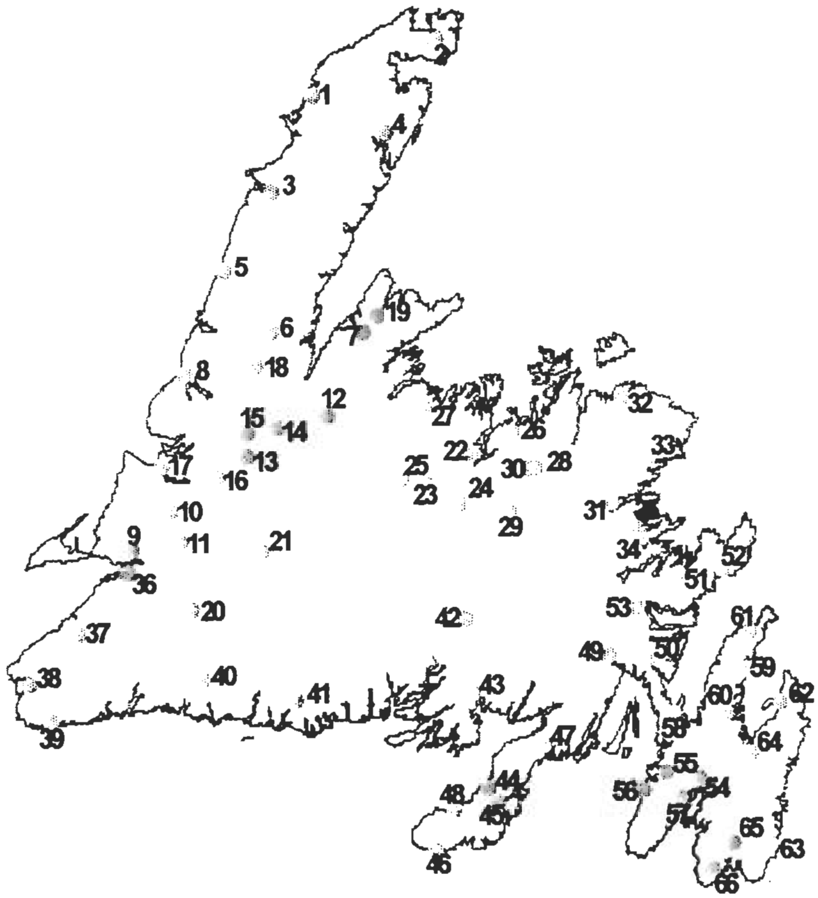
[4] In the next five cells, *Cell I9* to *Cell I13*, the user enters the indices of a minimum of one (1) and a maximum of five (5) gauges which will be used to estimate the average storage-yield curve for the site. The locations of the gauges and their indices are shown in Figure 5. If less than 5 gauges are chosen, the cells with no gauge selected should have a value of 0 entered.

As discussed in Section 3.3, the user should select gauges that are located as close as possible to the site. The chosen gauged watersheds should also be physiographically similar or as similar as possible to the target watershed in terms of, in order of significance, drainage area, fraction of drainage area covered by lakes, fraction of drainage area controlled by lakes and swamps, fraction of area covered by forests, and mean annual runoff. These parameters for the selected gauged watersheds are provided in *Cells B9* to *G13*. There are no strict rules to follow to determine similarity. The user may experiment with a number of combinations of gauges to determine the sensitivity of the resulting storage requirement (*Cell I21*) to the gauges selected. One indicator of this sensitivity is the storage fraction, SF, as estimated from each selected gauged watershed. These values are given in *Cell H9* to *Cell H13*.

[5] In the next cell, *Cell I14*, the user has the option of entering the estimated mean annual runoff of the site watershed based on the isolines shown in Figure 2 (by entering "1") or by having the spreadsheet automatically calculate the average mean annual runoff calculated for the selected gauged watersheds as an estimate (by entering "0").

[6] If in Step **[5]**, the user has entered "1" to indicate that mean annual runoff will be user-specified, then the user enters the estimate in the next cell, *Cell I16*. If, on the other hand, the user has entered "0", the user can ignore this cell, and the spreadsheet shows the calculated mean annual runoff for the selected gauged watersheds in the next cell below, *Cell I17*.

1	02YA001
2	02YA002
3	02YC001
4	02YD002
5	02YE001
6	02YG001
7	02YG002
8	02YH001
9	02YJ001
10	02YJ003
11	02YK002
12	02YK005
13	02YK007
14	02YK008
15	02YL001
16	02YL004
17	02YL005
18	02YL008
19	02YM003
20	02YN002
21	02YN003
22	02YO006
23	02YO007
24	02YO008
25	02YO010
26	02YO012
27	02YP001
28	02YQ001
29	02YQ004
30	02YQ005
31	02YR001
32	02YR002
33	02YR003



34	02YS003
35	02YS005
36	02ZA001
37	02ZA002
38	02ZA003
39	02ZB001
40	02ZC002
41	02ZD002
42	02ZE004
43	0EZF001
44	02ZG001
45	02ZG002
46	02ZG003
47	02ZG004
48	02ZG005
49	02ZH001
50	02ZH002
51	02ZJ001
52	02ZJ002
53	02ZJ003
54	02ZK001
55	02ZK002
56	02ZK003
57	02ZK004
58	02ZK005
59	02ZL003
60	02ZL004
61	02ZL005
62	02ZM006
63	02ZM009
64	02ZM016
65	02ZN001
66	02ZN002

Figure 5 Index of Stations with Updated Storage-Yield Curves

[7] The required storage requirement is displayed in the cell on the last line, *Cell I21*. This value is rounded to the nearest 10,000 m^3.

Cell I18 provides the value of the mean annual flow from the target watershed based on either the user-specified or spreadsheet-calculated mean annual runoff.

Cell I19 provides the value for the yield fraction which is calculated as the user-specified yield (*Cell I5*) divided by the mean annual flow (*Cell I18*).

Cell I20 provides the value for the calculated average storage fraction based on the selected gauges and user-specified or spreadsheet-calculated mean annual runoff.

3.6 Summary

This chapter has presented the updated non-dimensional storage-yield curves for 66 gauged watersheds. A comparison of these curves with those from the previous assessments shows that the new curves give slightly lower storage requirements for a given yield. There are however, within a specified area, smaller deviations between the updated individual curves than between those of the previous assessments.

A Lotus 1-2-3 spreadsheet was developed to allow a user to select specific gauged watersheds for use as predictors for determining storage-yield curves at ungauged sites. The spreadsheet is described and some guidelines are provided on the selection of gauged watersheds. The spreadsheet included in this guide can be used to provide a preliminary estimate of storage requirement for a desired yield at an ungauged site.

References

1. Government of Newfoundland and Labrador, Department of Environment and Lands, Water Resources Management Division. **Regional Water Resources Study of the Eastern Avalon Peninsula**. Report WRD-SW-1-1 (Acres International Limited, 1987).

2. Government of Newfoundland and Labrador, Department of Environment and Lands, Water Resources Management Division. **Regional Water Resources Study of the Western Avalon Peninsula**. Report WRD-SW-1-2 (Acres International Limited,1988).

3. Government of Newfoundland and Labrador, Department of Environment and Lands, Water Resources Management Division. **Regional Water Resources Study of the Bonavista Bay Area**. Report WRD-SW-1-3 (ShawMont Newfoundland Limited, 1989).

4. Government of Newfoundland and Labrador, Department of Environment and Lands, Water Resources Management Division. **Regional Water Resources Study of the Northern Peninsula and Humber Valley**. Report WRD-SW-1-4 (Acres International Limited, 1990).

5. Government of Newfoundland and Labrador, Department of Environment and Lands, Water Resources Management Division. **Regional Water Resources Study of Notre Dame Bay Area and Central Newfoundland Region**. Report WRD-SW-1-5 (Nolan, Davies and Associates (1986) Limited, 1991).

6. Government of Newfoundland and Labrador, Department of Environment and Lands, Water Resources Management Division. **Water Resources Study of the Burin Peninsula and Fortune Bay Area**. Report WRD-SW-1-6 (Acres International Limited, 1993).

7. Government of Newfoundland and Labrador, Department of Environment and Lands, Water Resources Management Division. **Water Resources Study of Southwestern Newfoundland Region**. Report WRD-SW-1-7 (Acres International Limited, 1994).

8. Government of Newfoundland and Labrador, Department of Environment and Lands, Water Resources Management Division. **Regional Flood Frequency Analysis for the Island of Newfoundland**. Report WRD-HM-90-I (1990).

9. Government of Newfoundland and Labrador, Department of Environment and Lands, Water Resources Management Division. **Characteristics and Estimation of Minimum Streamflows for the Island of Newfoundland**. Report WRD-HM-91-II (1991).

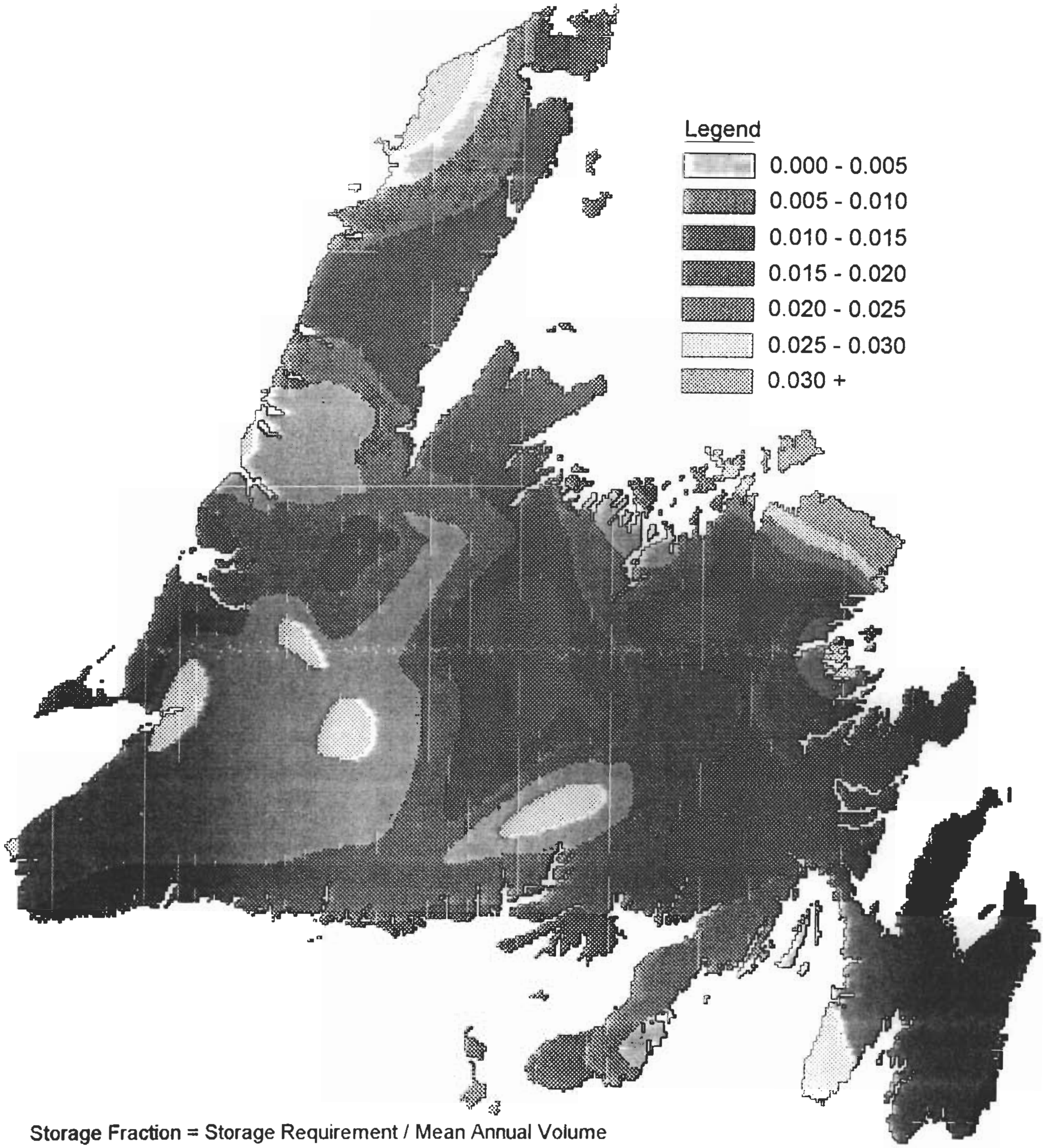
10. Government of Newfoundland and Labrador, Department of Environment and Lands, Water Resources Management Division. **Water Resources Atlas of Newfoundland**. (1992).

11. Atlantic Development Board. **Water Resources Study of the Province of Newfoundland and Labrador**. The Shawinigan Engineering Company Limited & James F. MacLaren Limited. Volumes 1-8 (1968).

Appendix A

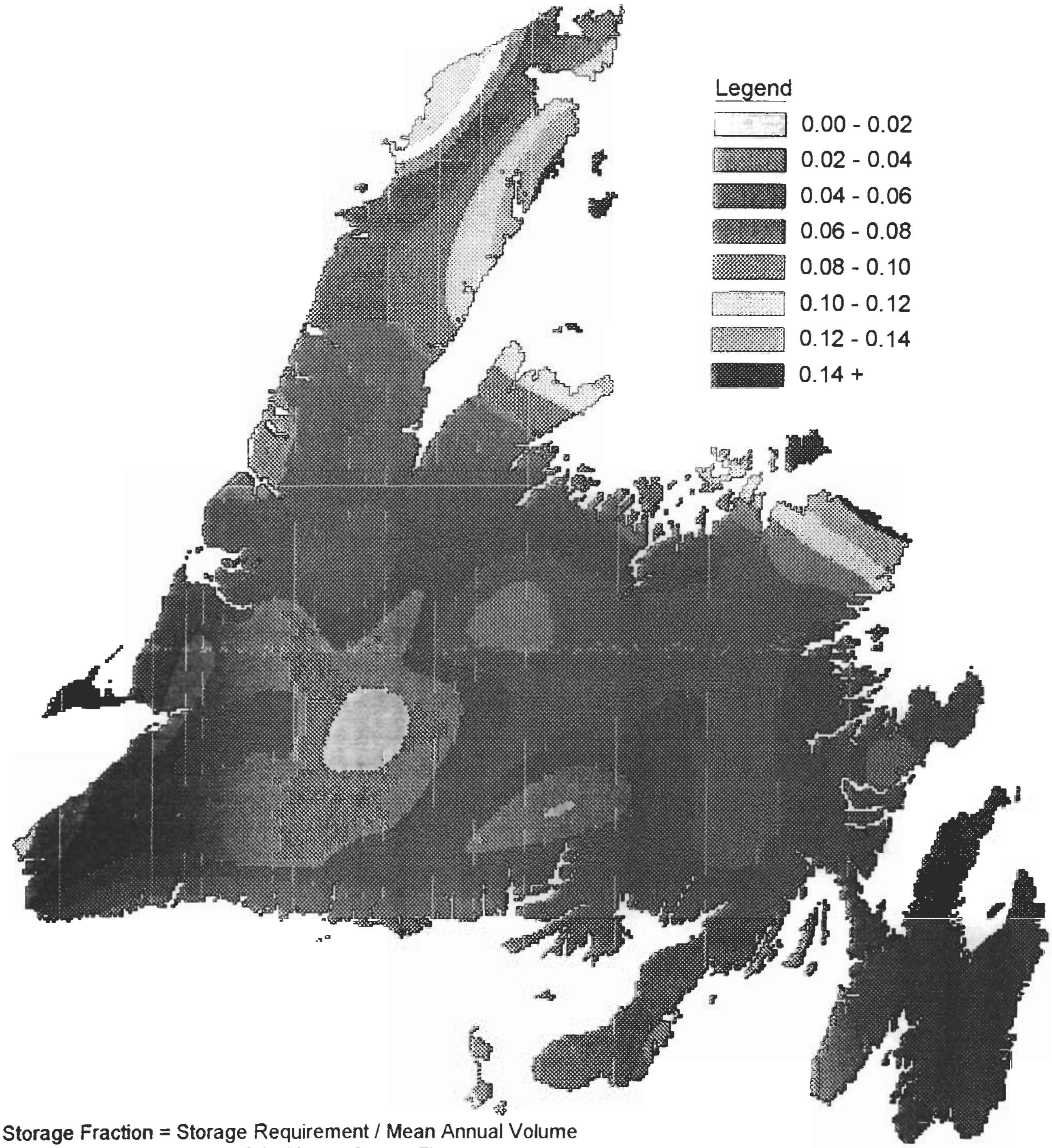
Storage-Yield Maps

Storage Fraction for Yield Fraction = 0.1



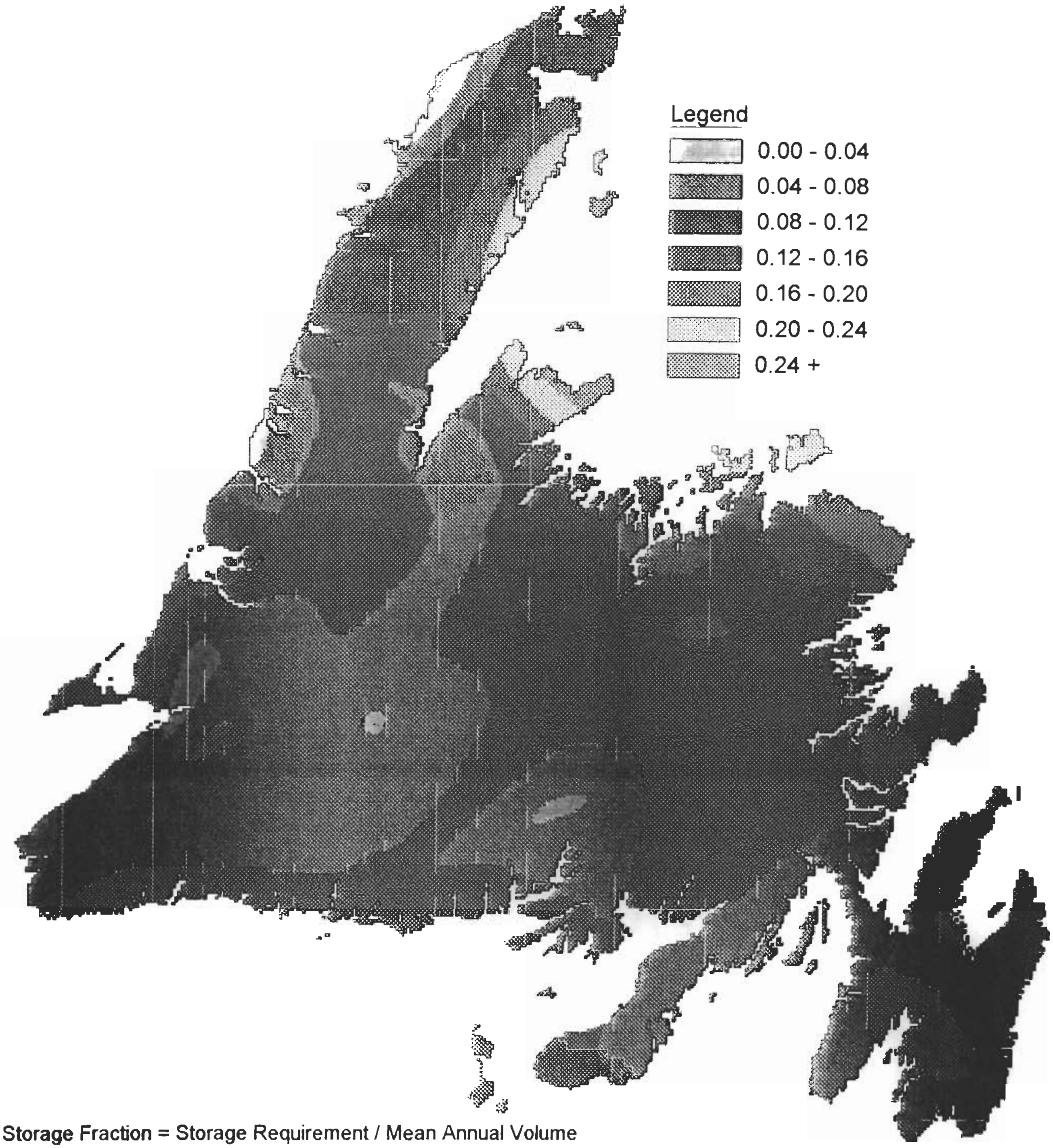
Storage Fraction = Storage Requirement / Mean Annual Volume
Yield Fraction = Required Yield / Mean Annual Flow

Storage Fraction for Yield Fraction = 0.3



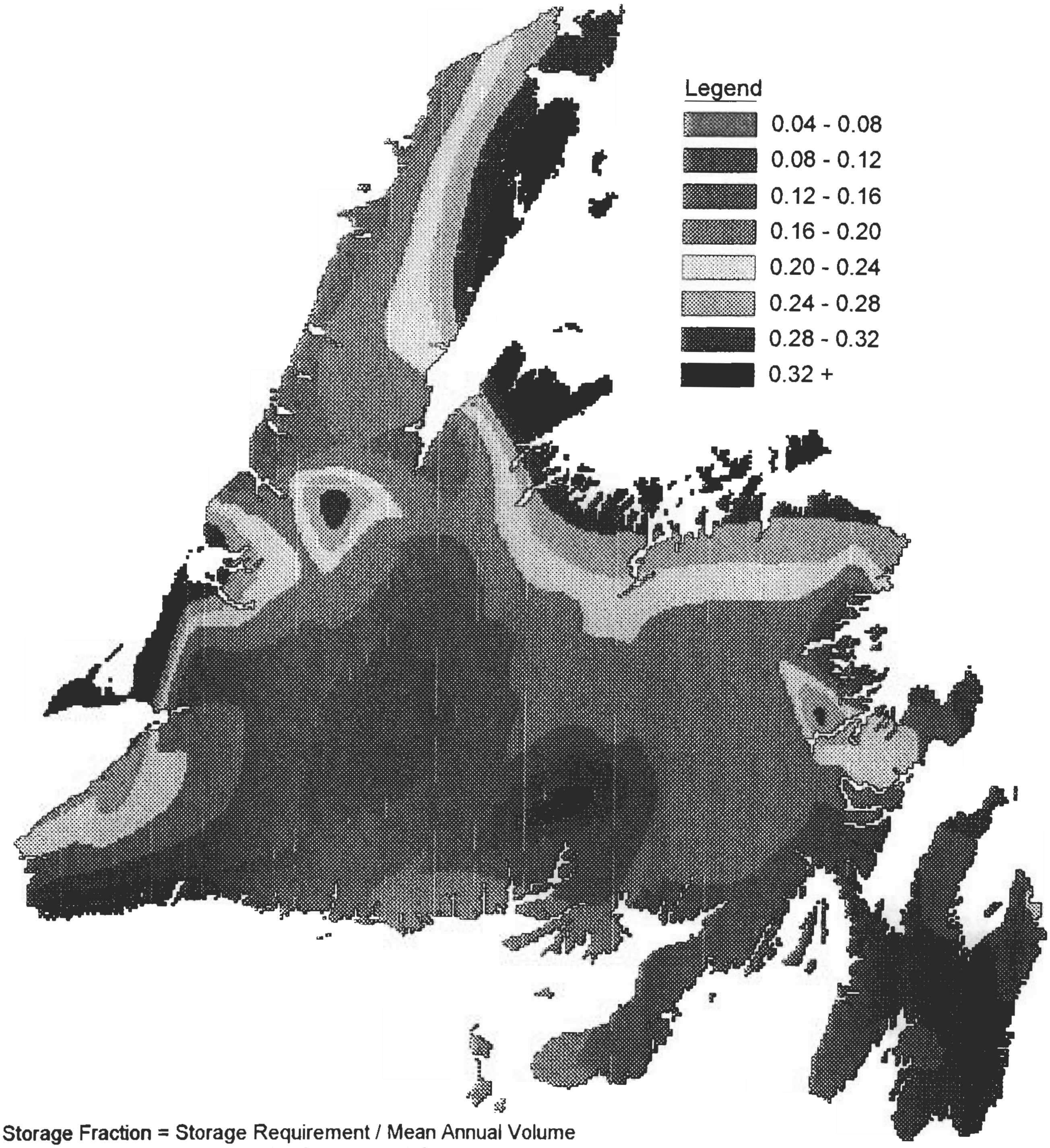
Storage Fraction = Storage Requirement / Mean Annual Volume
Yield Fraction = Required Yield / Mean Annual Flow

Storage Fraction for Yield Fraction = 0.4



Storage Fraction = Storage Requirement / Mean Annual Volume
Yield Fraction = Required Yield / Mean Annual Flow

Storage Fraction for Yield Fraction = 0.6



Storage Fraction = Storage Requirement / Mean Annual Volume
Yield Fraction = Required Yield / Mean Annual Flow