ESTIMATING MINOR PROJECT USE IN THE QU'APPELLE RIVER SYSTEM AT THE SASKATCHEWAN-MANITOBA BOUNDARY

PPWB REPORT NO. 75

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for the
Qu'Appelle River
SSARR Model SubCommittee

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FOREWORD

The natural flow of the Qu'Appelle River at the Saskatchewan-Manitoba boundary is estimated using the SSARR (Streamflow Synthesis and Reservoir Regulation) model. This model was adapted to the Qu'Appelle River as part of the natural flow studies made by the Calgary office of the WRB (Water Resources Branch) of Environment Canada.

In 1980, it was decided to revise the computational procedure to metric units. A subcommittee of the Committee on Hydrology, the SSARR Model Subcommittee, met on April 22, 1980 and identified eight problem areas that should be resolved before the model is converted to metric units. Subcommittee members agreed to resolve the following eight problems:

1) Check all existing and revised tables - PPWB Secretariat.

2) Check model configuration - WRB, Regina.

3) Define municipal sewage effluent - WRB, Regina.

4) Evaluate the use of reservoir regulation cards for lakes - Saskatchewan Environment.

5) Define the effect of overbank flow on natural flow computation - WRB, Regina.

6) Report on the use of index reservoirs - Saskatchewan Environment.

7) Define routing parameters for discharges under 100 c.f.s. - Not assigned.

8) Evaluate the use of SSARR vs SIMPAK models - Saskatchewan Environment.

This report summarizes the results of study number 6. Similar reports have been written to describe the results of study numbers 4 and 8. No report will be required for study numbers 1 and 2 but the needed technical revisions have been implemented.

With respect to study number 3, the Subcommittee, in March 1985, noted that return flow from the City of Regina is now measured at the outlet of the Regina tertiary treatment plant and that return flow from Moose Jaw now equals zero. Therefore, this question has also been answered.

Regarding study number 5, the present level of resources in Water Resources Branch, Regina office does not give them enough time to implement Saskatchewan Water Corporation's updated overbank flow parameters into the natural flow model. They will implement the overbank flow parameters as soon as is practical.

The subcommittee has agreed that there is no immediate need to develop routing parameters for discharge under 100 ft^3/sec (Study Number 7). That work may be done at a later date. Similarily, the task of converting the Qu'Appelle River SSARR Model to metric units is not cost-effective and may be eliminated.

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ESTIMATING MINOR PROJECT USE IN THE QU'APPELLE RIVER SYSTEM AT THE SASKATCHEWAN - MANITOBA BOUNDARY

The SSARR (Streamflow Synthesis and Reservoir Regulation) Model is used to estimate natural flow of the Qu'Appelle River at the Saskatchewan-Manitoba boundary. The effect that small storage projects have on consumptive use in the Qu'Appelle River is estimated using three index reservoirs. These three reservoirs are used individually to determine ratios of volume-of-water used to reservoir-capacity-for-use in estimating the total small project use in sub-areas and, ultimately, in the entire basin. Thus these ratios are, in fact, used to calculate small project use for the 32 398 dam^3 of small project storage in the Qu'Appelle River Basin.

The Province of Saskatchewan has prepared a report entitled "Qu'Appelle River System - Review of Index Reservoirs". This report, dated April 1984, reviews the use of these reservoirs and describes how they are used to estimate small project use in the basin. It recommends a methodology whereby the project use estimates may be improved. The report is attached to this report as Appendix A.

The purpose of that study was stated as follows:

> *"to determine if the selected index reservoirs are needed to estimate minor project storage in the Qu'Appelle River basin. The index reservoirs may not be indicative of the entire basin and the minor project storage may be small enough to be approximated without destroying the accuracy of the natural flow estimated at the Saskatchewan-Manitoba boundary."*

This report will propose an alternate <u>interim</u> method that may be used to estimate small project use by storage reservoirs with the understanding that the methodology will be reviewed when more information has been gathered. The report proposes to answer four questions:

A. Does small project use and its effect on natural flow of the Qu'Appelle River need to be estimated?

B. Are index reservoirs the best way to estimate small project use?

C. Is the methodology now being used acceptable and, if not, is there another methodology that may be used?

D. Is there a possibility that, at some future date, the use of small index reservoirs may be terminated?

A. <u>Does small project use and its effect on natural flow of the Qu'Appelle River need to be estimated?</u>

The provincial report in Appendix A demonstrates that small project use is an appreciable part of natural flow in the Qu'Appelle River Basin, particularly in low flow years. Total reservoir storage capacity for minor projects in the Qu'Appelle River Basin of 32 398 dam^3 is 17% of the mean annual natural flow in the basin as determined at Welby. This fact alone is sufficient justification to indicate that some estimate should be made to determine how much of that total minor project storage capacity is utilized each year. In drier than normal apportionment periods, such as 1981-82, the total natural flow is less than the total storage capacity of the minor projects so an approximation that is not sensitive to the water actually used by the projects is not acceptable (see Table 1).

TABLE 1

RECORDED AND NATURAL FLOW OF THE QU'APPELLE RIVER * (in dam^3)

Apportionment Period	Recorded Flow at Welby	Diverted from Lake Diefenbaker	Natural Flow at Welby
1978-79	85 500	49 300	67 700
1979-80	381 500	40 800	304 200
1980-81	101 500	88 000	70 900
1981-82	59 500	140 000	29 700
1982-83	295 000	37 800	194 000
1983-84	327 000	56 400	246 000

* Each apportionment period covers the 12 months from April 1 of one year to March 31 of the next year.

The provincial report has described both the situation and the problem. At the present level of use, Saskatchewan is using considerably less than 50% of natural flow. In fact in 1981-82, a dry year, 140 000 dam^3 was diverted from Lake Diefenbaker giving a recorded flow of 59 500 dam^3 at the Saskatchewan-Manitoba boundary. This diversion was twice as much as the natural flow of 29 700 dam^3 in the same period.

Passing 50% of the natural flow to Manitoba does not appear to be a problem at the present time, but it is necessary to document the percentage of natural flow that is passed each year because of possible future uses in the Qu'Appelle River basin. Both a continuing record of natural flow and a method of estimating small project use that is workable and easily handled by Water Resources Branch are needed. Even if it is only an interim method, some form of measurement is needed. The only method presently available is based on a reservoir storage index. If that method is not used, one must rely on a mechanical approach that may not provide for sufficient variability, particularly in drought years.

B. Are index reservoirs the best way to estimate small project use?

Index reservoirs appear to be the best alternative available at the present time. Ideally each water use should be tabulated individually and added or subtracted from the recorded flows. This approach is neither practical nor cost-effective. Therefore, some approximation of small project use must be made based on the information on hand or available through a monitoring program. Such an approach might include parameters or indices based on drainage areas tributary to each reservoir, unit runoff relationships, capacity considerations, licenced uses, etc.

The years of record available on index reservoirs now covers the apportionment period from 1977 to 1985 inclusive. They indicate that these reservoirs are sensitive to drought in a manner similar to the estimated natural flow (see Table 2). Reservoir use is higher when water is available and lower when water is in short supply. Based on these observations, it must be concluded that, until a better methodology can be made available, index reservoirs provide the best interim method available to estimate small project use in the Qu'Appelle River Basin.

TABLE 2

WATER STORED BY INDEX RESERVOIRS
DURING THE ANNUAL APPORTIONMENT PERIOD
(in cubic decametres)

Apportionment Period *	Lumsden	Avonlea	Silton
1977-78	0.07	0.47	14.38
1978-79	1.63	7.03	11.53
1979-80	6.20	12.38	13.36
1980-81	2.43	5.21	13.17
1981-82	1.57	nil	1.44
1982-83	5.33	12.52	13.20
1983-84	2.71	11.08	19.13
1984-85	1.62	4.03	8.41
Average Use	2.69	6.59	11.83
Median Use	2.03	6.12	13.18

* Each apportionment period covers the 12 months from April 1 of one year to March 31 of the next year.

C. Is the methodology now being used acceptable and, if not, is there another methodology that may be used?

Having examined the concerns addressed in the report prepared by Saskatchewan Environment and having looked at natural flow estimates records from 1978 to 1984, with special reference to the way that index reservoirs were used to estimate natural flow, it must be concluded that the present methodology is not acceptable.

The uses in cubic decametres at each index reservoir are shown in Table 2. These figures are based on information supplied by Mr. B. Yee, Boundary Waters Engineer, Water Resources Branch, Environment Canada. They indicate that the ratio of annual use of water in these three reservoirs to the reservoir's storage capacity varies significantly between reservoirs. There is always some water stored in the Lumsden reservoir but that storage averages only one third of the reservoir's capacity. The storage in the Avonlea reservoir varies greatly from zero to almost the full storage capacity and in an average year totals a little less than one half of the reservoir capacity. In the Silton reservoir, however, storage is usually 80% of the reservoir capacity and, with the exception of the two very dry years in 1981 and 1984, storage is consistently high. The three reservoirs appear to indicate three different types of small reservoir storage based on differing factors related to use, supply and storage. They are used individually, however, to determine uses on many such small reservoirs. It may be assumed that the average of these three types of use will be more representative of the average of any additional similar reservoirs. Therefore, it is concluded that the index reservoirs will provide a more representative index of average reservoir use in the basin if they are used in combination rather than singly.

The foregoing discussion suggests that some improvements to the existing method or some other method are needed to provide a more representative estimate of water use for minor storage reservoirs. If another method will adequately estimate small project water use on a year to year basis, it should replace the existing method. Five alternate methods have been considered.

1) Assume that small reservoir annual use is equal to the reservoir capacity as documented in Water Rights files. This method initially appears attractive. It is simple and straight forward to apply but it is both inaccurate and misleading. The information collected from index reservoirs over the past eight years indicates that water use is variable and is a direct function of available streamflow, not just the total reservoir capacity. Therefore, a better measure is required.

2) Assume that annual uses are equal to the licenced use for the project. The suggestion has been made that use should be based on the total annual use allocated to these reservoirs. This proposal has the same weakness as the one involving reservoir capacity. It applies a constant use factor to uses that are determined from observations. Licenced use and total water use for each of the three index reservoirs are shown in Table 3.

TABLE 3

LICENCED WATER USE

Reservoir	Licenced Use ac-ft	Licenced Use dam^3	Evaporation Use ac-ft	Evaporation Use dam^3	Total Use ac-ft	Total Use dam^3
Lumsden (WR File 7517) NW 21-18-21-W2	2	2.46	1	1.23	3	3.70
Avonlea (WR File 3530) NE20-11-23-W2	1	1.23	4	4.93	5	6.17
Silton (WR File 7930) NW19-21-21-W2	4	4.93	2	2.46	6	7.40

* Note: Licences are recorded in acre-feet in Saskatchewan Water Corporation files.

Recorded uses for these three index reservoirs show an average annual use that is 125% of licenced use. There is considerable variability from reservoir to reservoir with the Lumsden uses being lower than the licenced value, Avonlea higher and Silton over 50% higher than licenced use. These figures provide the same end result as if reservoir capacity was used but do not allow for variable uses in drier than average years. There is sufficient variability in reservoir use, as illustrated in Table 2, to make the approach unuseable.

3) Use the approach recommended by Saskatchewan Environment report.

The concept of the revised approach based on a relationship of water use to drainage area (Appendix A) has some merit and might improve the reliability of small project use estimates. However, the time needed to produce water use estimates based on this proposed approach will, initially, be large because drainage areas would have to be determined for each project. Once drainage areas are determined, subsequent calculations would require little time or effort if the process was computerized. If the tributary drainage area was defined for each project, it would be possible to further refine the approach by considering individual projects. The refined approach could then be applied step-by-step as follows:

a) The unit runoff (UR) is determined for each index reservoir as the amount of runoff (i.e. sum of water stored plus spills if any) divided by the appropriate drainage area.

b) The ratio (R) of water use to project capacity is calculated for each index reservoir as recorded annual water use (i.e. water retained) divided by the index reservoir capacity.

c) The water use for each individual minor project is calculated as the minimum of either available flow (i.e. UR times minor project drainage area) or apparent water use (i.e. R times minor project capacity) where UR and R could be values for a specific index reservoir or the average of values for appropriate index reservoirs.

d) The total minor project use within the basin or sections of the basin is determined by summing individual project uses as calculated in step c.

It should be noted that this approach does not resolve the problems associated with oversized or undersized projects. That inadequacy may be better addressed if and when consistent licences are provided for all projects. Consideration could then be given to utilizing licenced amounts (or ratios involving licenced amounts) as a limitation on the amount of water actually "used" by minor projects.

4) <u>Modify the Existing Index Reservoir Methodology</u>

The concept of using index reservoirs is valid. It is the variability of uses in the three index reservoirs that renders it unacceptable. As each of the three reservoirs appears to indicate a different ratio of use to capacity it may be assumed that a methodology averaging the ratios will be more representative of small project consumptive use.

It is suggested that a combined ratio of recorded use over total capacity for each of the three index reservoirs will give a ratio of use to capacity that can be applied to all minor storage projects in the basin, either by sector or by applying one adjustment factor to recorded streamflow at the end of the calculation process. If the latter alternative is implemented, care must be taken to ensure that artificially large inflow residuals are not created because of the computation procedure. Method four may be applied step-by-step as follows:

a) The ratio of use to storage is calculated individually for each of the three reservoirs as recorded annual use over total storage.

b) The three individual reservoir storage ratios are added and divided by three to provide one ratio for small project use (see Table 4).

TABLE 4

*** WATER STORED DURING THE APPORTIONMENT PERIOD AS A RATIO OF RESERVOIR CAPACITY**

Apportionment Period	Lumsden	Avonlea	Silton	Total Calculated Small Project Use
Capacity =	7.6 dam^3	12.5 dam^3	13.4 dam^3	Total = 33.5 dam^3
1977-78	0.01	0.04	1.07	0.37
1978-79	0.21	0.56	0.86	0.54
1979-80	0.82	0.99	1.00	0.94
1980-81	0.32	0.42	0.98	0.57
1981-82	0.21	0	0.11	0.11
1982-83	0.70	1.00	0.99	0.90
1983-84	0.36	0.89	1.43	0.89
1984-85	0.21	0.32	0.63	0.39

* Records indicate that some reservoirs were filled, used and refilled in the same apportionment period.

c) The use-ratio multiplied by the reservoir capacity provides an estimate of small project use in the basin (see Table 5). These uses are added to recorded flow to provide an estimate of natural flow. The small project use appears to be a function of the natural flow. It is reasonable to assume that annual reservoir storage and use will be a function of available water.

TABLE 5

CALCULATED SMALL PROJECT USE IN DAM^3

Apportionment Period	Using Water Resources Branch Method *	Using Proposed Method
1978-79	13 894	17 495
1979-80	29 374	30 454
1980-81	13 986	18 467
1981-82	8 085	3 564
1982-83	27 823	29 158
1983-84	22 463	28 834

* The method now used to estimate small project use.

Thus, in years of low flow such as 1981-82, reservoir storage and consumptive use will be smaller; in years such as 1979-80, larger. These two years showed both the largest and smallest natural flows and observed use. Also, after a critically dry year such as 1981-82, it is reasonable to assume that more water would be impounded in 1982-83 in these reservoirs to recover from the low flow deficit. Consequently, small project use in 1982-83 was larger than would be normally expected, again confirming the reasonableness of the proposed method.

A ratio of this type can also be used on an area by area basis to provide estimates of small project use in each of the sub-basin areas.

All three index reservoirs, however, are located in the Upper Qu'Appelle Basin. Recommendation No. 3 of the report prepared by D.R. Richards (see page A-15), refers to the need to establish an additional index reservoir in the Lower Qu'Appelle Basin. That recommendation is valid and will be reiterated in this report.

5) A Graphical Relationship Between Use and Flow

There appeared to be some relationship between flow and small project use so the possibility of establishing a graphical relationship was investigated. Small project uses as calculated by the existing procedure and as calculated using method 4 were plotted against each of three flow parameters (natural flow, recorded flow and recorded flow minus water diverted from Lake Diefenbaker) assuming that a reasonable correlation might exist in one of these graphical relationships.

Based on the limited amount of data available, better results were obtained using method 4. The best relationship using this method was based on recorded streamflow minus water diverted from Lake Diefenbaker. The approach gave a curve that rose sharply to an average flow level and flattened out as use approached the total minor project capacity of 32 938 dam^3. The curve provides the type of graphical relationship that one would expect. In a continuing sequence of high flow years, small project use decreased at high flow levels because the reservoirs, having been filled in the previous apportionment period, would require less make-up water in the current year.

The six points shown on the curve, in Figure 1, are too few to draw a reliable curve of this type. In 1990, when another six years are available, the proposed interim methodology should be reviewed to determine if, based on the additional information gathered, an improved approach might be developed to estimate small project use.

Furthermore, the total annual cost of monitoring these stations is less than $3 000 so the index reservoir approach can be continued at a reasonable cost until some better method has been found.

D. Is there a possibility that at some future date the use of small index reservoirs could be terminated?

Having reviewed the above five methods, it is suggested that method 4 be implemented on an interim basis until enough data is gathered to relate use to flow as proposed in Method 5, or to select a better method to estimate consumptive use. In 1990, after additional information on annual use at these reservoirs has been gathered, the methodology should be reviewed. No decision on the retention or termination of these reservoirs should be made until that study has been completed.

RECOMMENDATIONS

1. Based on the information contained in this report and Appendix A, it is recommended that the Water Resources Branch of Environment Canada continue to operate the three index reservoirs for the purposes of the Prairie Provinces Water Board.

2. It is recommended that the methodology described as methodology number 4 be used as an interim approach to estimate minor project use starting in the year 1985/86.

3. It is recommended that this interim method of estimating consumptive use be reviewed in 1990 when sufficient information from the index reservoirs will be available to determine whether small project uses can be realistically estimated. This review will include a more thorough analysis of the relationship between small project use and reservoir capacity, licenced use and contributing drainage area.

4. It is recommended that an additional index reservoir be established in the lower Qu'Appelle River Basin to replace the "Kaposvar" index reservoir that became inoperable when the owner breached the dam. All four index reservoirs could be used jointly to determine the average use ratio. (This recommendation was not discussed in detail in the Main Text of the report but it is important that some measure of water use in the eastern part of the Qu'Appelle River Basin is included in the natural flow evaluation).

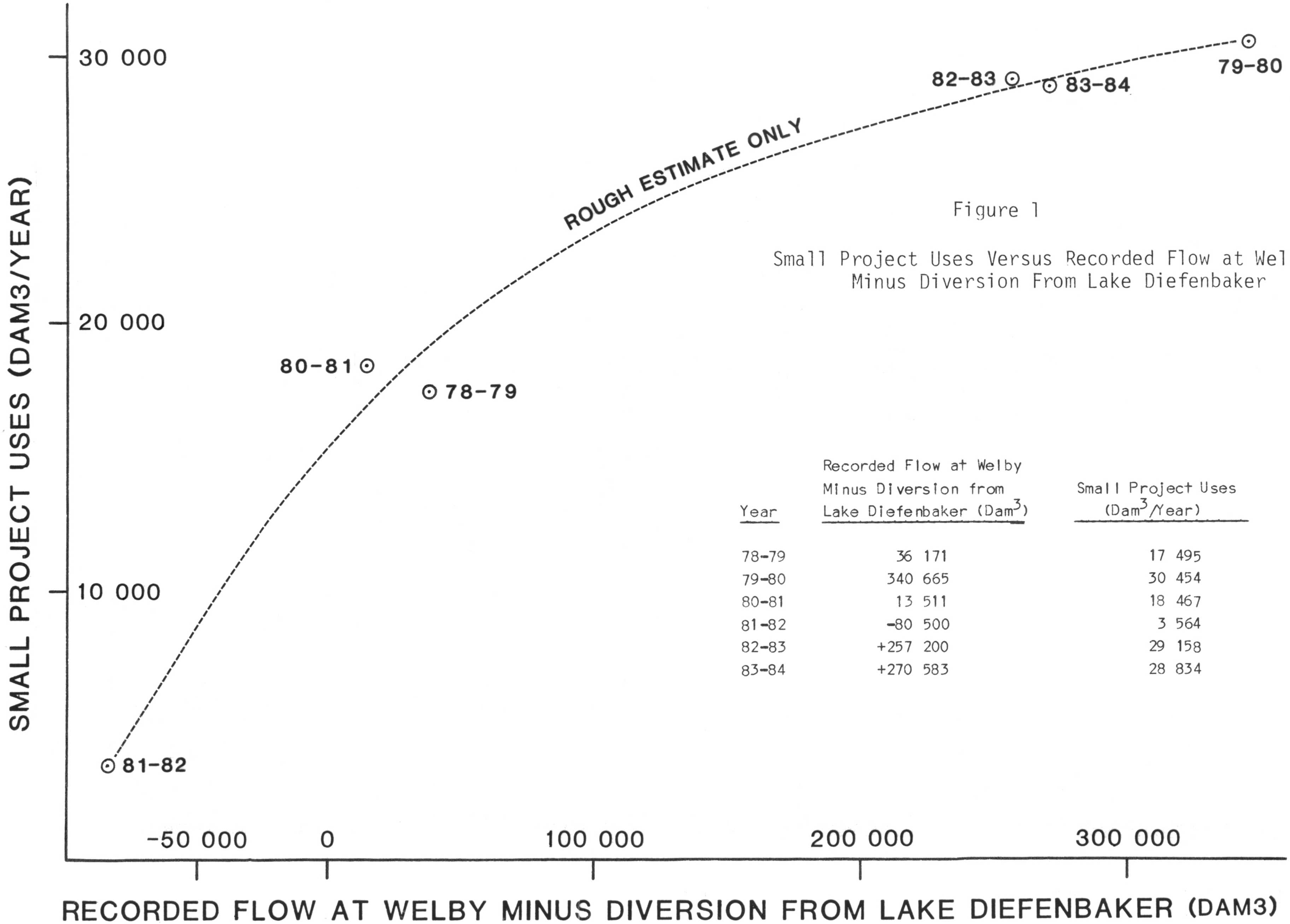
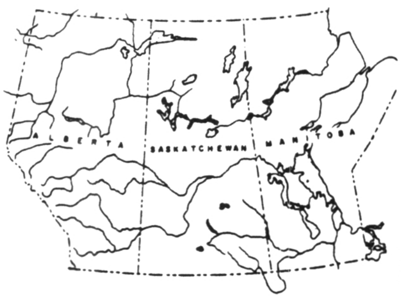


Figure 1

Small Project Uses Versus Recorded Flow at Welby Minus Diversion From Lake Diefenbaker

Year	Recorded Flow at Welby Minus Diversion from Lake Diefenbaker (Dam^3)	Small Project Uses (Dam^3/Year)
78-79	36 171	17 495
79-80	340 665	30 454
80-81	13 511	18 467
81-82	-80 500	3 564
82-83	+257 200	29 158
83-84	+270 583	28 834



Appendix A

QU'APPELLE RIVER SYSTEM REVIEW OF INDEX RESERVOIRS

QU'APPELLE RIVER SYSTEM

REVIEW OF INDEX RESERVOIRS

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April, 1984

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Chapter I

INTRODUCTION

The 1975 report 1/ on Natural Flow in the Qu'Appelle River Basin at the Saskatchewan-Manitoba Boundary recommended "that the depletion of runoff due to storage in small reservoirs be estimated from four index reservoirs". It identified the Moose Jaw River, Wascana Creek, Last Mountain Lake and Kaposvar Creek basins as requiring index reservoirs due to the number of minor project storage reservoirs in those basins. In 1976, Water Survey of Canada conducted an investigation into the small reservoirs in each of these basins to select one reservoir from each basin to act as the index 2/. The Avonlea, Lumsden, Silton and Esterhazy Index Reservoirs were selected in this study. The Esterhazy Index Reservoir was breached by the owner in 1976 or 1977 and thus has not been available for use to calculate the minor project storage.

Beginning in March, 1977, these index reservoirs were monitored during the spring runoff period using manual gauge readings. The volume of water stored in each index reservoir during the runoff was calculated from stage-capacity curves. The ratio of volume of water stored versus capacity at full supply level (FSL) was calculated for each index reservoir and this ratio was multiplied by the minor project capacity in the respective sub-basins (sub-basins to the Qu'Appelle were assigned index reservoirs to

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1/ "Qu'Appelle River at Saskatchewan-Manitoba Boundary Natural Flow" Department of Environment. Water Survey of Canada and Atmospheric Environment Service, December, 1975.

2/ "Selection of Index Reservoirs in Kaposvar Creek, Last Mountain Lake, Moose Jaw River, Wascana Creek Basins:" Water Survey of Canada, Saskatchewan District, November, 1976 represent minor project storage) to determine the total water stored in the minor projects. The total volume stored in each sub-basin was prorated over the month(s) in which the storage occurred and entered into the natural flow model as daily flows in cubic feet per second (cfs).

This study was conducted to determine if the selected index reservoirs are needed to estimate minor project storage in the Qu'Appelle River basin. The index reservoirs may not be indicative of the entire basin and the minor project storage may be small enough to be approximated without destroying the accuracy of the natural flow estimated at the Saskatchewan-Manitoba boundary.

Chapter II

CALCULATION OF STORAGE VOLUMES

A. STORAGE AND RUNOFF IN THE BASIN

Data have been collected on the index reservoirs in the Qu'Appelle basin since 1977 and an analysis of the results is shown in Table 1.

Table 1

Ratio of Water Stored at the Annual Peak Reservoir Elevation to Reservoir Capacity at FSL for Qu'Appelle Basin Index Reservoirs

Year	Index Reservoir		
	Avonlea	Lumsden	Silton
1977	0.03	0.00	1.07
1978	0.52	0.21	1.11
1979	1.12	0.81	1.20

It can be seen from Table 1 that, depending on the magnitude of the runoff, the storage in small reservoirs may approach or even exceed the reservoir capacities at full supply level. Although storage exceeds FSL in some instances, Water Survey of Canada (WSC) uses 1.00 as the ratio since the assumption is that the index reservoir will automatically spill the water temporarily stored above FSL.

Based on information obtained from WSC, data were assembled on minor storage capacities in the various sub-basins. These capacities are shown in Table 2. The total capacity of minor project storage in the Qu'Appelle basin is 32 398 x 10^3 m^3.

Table 2

Capacities of Minor Project Storage
in the Qu'Appelle Basin

Area	Project Capacities[1]	Total Capacities[1]
Moose Jaw River Basin Storage[2]	13 543	13 543
Lumsden to Flying Creek Offstream Storage	507	
Wascana Creek Basin	5 370	
Sub Total[3]		5 877
Last Mountain Lake Basin Storage[4]	3 753	3 753
Craven to Below Loon Creek Storage	49	
Indian Head Creek Basin Storage	335	
Echo Creek Basin Storage	258	
Jumping Deer Creek Basin Storage	41	
Pheasant Creek Basin Storage	100	
Pearl Creek Basin Storage	26	
Ekapo Creek Basin Storage	440	
Kaposvar Creek Basin Storage	1 988	
Cutarm Creek Basin Storage	5 988	
Sub Total[5]		9 255
Total		32 398

1/ Capacities are in $m^3 \times 10^3$ at FSL.

2/ Avonlea Index Reservoir is used to compute minor project storage in this sub-basin.

3/ Lumsden Index Reservoir is used to compute minor project storage in these sub-basins.

4/ Silton Index Reservoir is used to compute minor project storage in this sub-basin.

5/ Minor project storage in these sub-basins is estimated using the other index reservoirs due to the breaching of the Esterhazy Index Reservoir.

The Saskatchewan-Nelson Basin Board (SNBB) studied natural flow on the Qu'Appelle River at Welby and reconstructed natural flows for the period 1912 to 1967. Using the "C" files, in which no random factors were used with the correlations, SNBB determined that the mean annual natural flow at Welby was 189 489 x 10^3 m^3. This volume is an indication of the order of magnitude of annual natural flow to be expected, and indicates that the minor project storage capacity is about 17 per cent of the mean annual natural flow. Thus, it is important that minor project storage be calculated as accurately as possible.

The sub-basins originally represented by the Esterhazy Index Reservoir are now calculated using the Silton Index Reservoir. Although in some years (i.e. 1968, 1971, 1973 and 1978) these sub-basins had runoff of similar magnitudes, in other years (i.e. 1965, 1966, 1972, 1975 and 1977) the differences in runoff magnitude would cause inaccuracies in calculating minor project storage. To be more precise in calculating these storages, another index reservoir would have to be set up in the lower Qu'Appelle. Such a reservoir should be established as soon as possible.

B. CALCULATION OF MINOR PROJECT STORAGE

1. Storage Using the Existing Method

The three index reservoirs now in use have the following capacities at FSL: Avonlea - 12.5 x 10^3 m^3, Lumsden - 7.6 x 10^3 m^3 and Silton - 13.4 x 10^3 m^3. These index reservoirs are used to calculate storage of many minor projects. Some reservoirs have capacities many times larger than the index reservoirs and small inaccuracies in the method of calculating the filling of the index reservoirs will have a major effect on the calculated volume of water stored in minor projects in the basin and hence on the calculated natural flow.

The effect of inaccuracies may be illustrated using, as an example, the Silton Index Reservoir which recorded a volume of water stored at the annual peak reservoir elevation greater than the reservoir capacity at FSL in each of the three years from 1977 to 1979 (See Table 1). The relative magnitude of the annual runoff from this region in these three years, using recorded volumes of flow in the Arm River near Bethune was: 1977 - 289 x 10^3 m^3, 1978 - 5 430 x 10^3 m^3 and 1979 - 19 700 x 10^3 m^3. since the Silton Index Reservoir stored a volume of water equal to its capacity at FSL in each of these years the total minor project storage for the sub-basin in each of those years, using the existing method of calculation, would have been equal to the total storage capacity at FSL, or 3 753 x 10^3 m^3.

The 1977 runoff in this area was the lowest on record. The Silton Index Reservoir filled after the spring runoff period likely as a result of a rainstorm. Water supply in this area was much lower in 1977 than in 1979. It seems unlikely, therefore, that the 3 753 x 10^3 m^3 of minor project storage in the Last

Mountain Lake basin would be retained by the minor project reservoirs represented by the Silton Index Reservoir in both 1977 and 1979 since the 1977 runoff was so low compared to 1979. Thus, it is concluded that the existing method of calculating minor project storage over-estimates the volume of water stored in the minor projects.

2. Storage Using Drainage Area as a Factor

The size of the contributing drainage area has a bearing on the quantity of water which reaches a minor storage reservoir. The capacity of the reservoir determines the maximum amount of runoff which can be retained. The present theory of using an index reservoir method to determine minor project storage assumes that the relationship between the index reservoir capacity and its drainage area holds for all minor projects in the sub-basin which that index reservoir represents. However, this assumption does not always hold.

Using the Last Mountain Lake basin as an example, the Silton Index Reservoir has a capacity of 13.4×10^3 m^3 and an effective drainage area of 2.0 km^2 [3/]. Other reservoirs in this basin that were studied in the 1976 report to select the index reservoir had the following capacities and drainage areas:

3/ Effective drainage areas quoted in this report are from the Water Rights files of Saskatchewan Environment.

Location	Reservoir Capacity (m^3)	Effective Drainage Area (km^2)	Ratio of Reservoir Capacity/Effective Drainage Area ($m^3 \times 10^3/km^2$)
Bethune	16.7×10^3	274	0.06
Dilke	13.6×10^3	8	1.7
Strasbourg	24.7×10^3	13	1.9
Hatfield	27.2×10^3	20	1.36
Simpson	13.6×10^3	1	13.6
Silton	13.4×10^3	2	6.7

This variation in reservoir capacity versus drainage area reduces the accuracy of calculating minor project storage using index reservoirs and the present method.

To account for the drainage area factor, each minor project reservoir should be analyzed and an effective drainage area calculated. Using the sum of the individual drainage areas, and the volume of water stored in the index reservoir, the minor project storage can then be calculated using the following formula:

Equation 1: $$SMP_k = \frac{IRS_k \times MPEDA_k}{IREDA_k}$$

where SMP_k = total minor project storage in sub-basin "k" - $m^3 \times 10^3$

IRS_k = volume of water stored in the index reservoir of sub-basin "k" during the year - $m^3 \times 10^3$

$IREDA_k$ = effective drainage area contributing to the index reservoir sub-basin "k" - km^2

$MPEDA_k$ = total effective drainage area contributing to all minor project storage reservoirs in the sub-basin "k" - km_2

Use of this equation does not require that a change be made in the method of determining the amount of water stored in the index reservoir during runoff.

3. <u>Storage Modified for Available Capacity</u>

The index reservoirs not only provide an indication of the amount of water stored in minor project reservoirs each year, but also indicate the capacity to capture runoff based on carryover of water stored in the previous year. In equation 1 there is no limiting factor to account for the capacity to store runoff. This can be achieved by using the index reservoir to set a limit on available storage in the minor project reservoirs in the sub-basin. Thus if the index reservoir has the capacity to store 50 per cent of its capacity at FSL, this 50 per cent factor would limit the ability of the minor project storage reservoirs to store water to 50 per cent of their capacities at FSL. If this index reservoir captures only 40 per cent of its capacity (i.e. 10 per cent from full) then the minor project reservoirs would still be limited in their capacity to store water by the original 50 per cent of capacity, not the 40 per cent actually stored in the index reservoir.

4. <u>Application of the Three Calculation Methods</u>

A hypothetical example has been developed to illustrate the differences in the calculated volumes of water taken into storage in minor projects using the three methods:

- the existing method;
- using equation 1 directly; and
- using equation 1 but considering available storage as a limiting factor.

It is assumed that the hypothetical basin has an index reservoir with the following characteristics:

Capacity at FSL = 10×10^3 m^3

Effective drainage area (IREDA) = 3 km^2

Volume of water stored in the year studied (IRS) = 7×10^3 m^3

Capacity to store water before runoff = 8×10^3 m^3.

The list of minor projects in the hypothetical basin, their capacities at FSL and effective drainage areas (MPEDA) are shown in columns 1 to 3 in Table 3.

Using the existing method, the calculation shows that the index reservoir stored 70 per cent of its total storage volume and therefore the minor projects stored 70 per cent of the total volume for all projects in the sub-basin. This method would result in a charge of 126.0×10^3 m^3 for the sub-basin. The total volume at FSL of all projects in the hypothetical sub-basin is 180×10^3 m^3. The results of the calculation are shown in column 4 in Table 3.

Table 3

Minor Project Storages in Hypothetical Basin

Hypothetical Basin Characteristics			Storage Calculations Using Existing Method	Storage Calculations Using Equation 1			
					No Storage Correction	Adjusted for Available Storage	
Project	Capacity at FSL ($m^3 x 10^3$)	Effective Drainage Area MPEDA (km^2)	Volume Stored ($m^3 x 10^3$)	Total Runoff ($m^3 x 10^3$)	Volume Stored ($m^3 x 10^3$)	Available Capacity ($m^3 x 10^3$)	Volume Stored ($m^3 x 10^3$)
Col. 1	2	3	4	5	6	7	8
Index	10	3	7.0	7.0	7.0	8.0	7.0
1	15	3	10.5	7.0	7.0	12	7.0
2	20	100	14.0	233.0	233.0	16.0	16.0
3	5	1	3.5	2.3	2.3	4	1.5
4	5	15	3.5	35.0	35.0	4	4.0
5	25	5	17.5	11.7	11.7	20	11.7
6	100	2	70.0	4.7	4.7	80	4.7
Totals	180	129	126.0	300.7	300.7	144	52.7

The main problem with the existing method may be seen from an examination of columns 3 and 4 in Table 3. Regardless of the size of the drainage area, only 70 per cent of the storage capacity for each project is assumed to have been filled. Projects 1 and 2 show the inconsistency of this procedure - a basin with a contributing area of 100 km^2 only fills a 20×10^3 m^3 reservoir to 70 per cent of its capacity, the same ratio as a reservoir three-quarters the size but with ony 3 km^2 of contributing area. Clearly, the results are not consistent or logical.

Using equation 1 without any adjustment for the amount of storage capacity actually available gives quite a different result. In the hypothetical example the first term in equation 1, which is actually an expression of unit yield, would be:

$$\frac{IRS}{IREDA} = \frac{7 \times 10^3}{3} = 2.33 \times 10^3 \frac{m^3}{km^2}$$

The total runoff to each project, shown in column 5 in Table 3, is a product of the unit yield as calculated above and the effective drainage area for that project. Without considering the amount of storage capacity actually available, the calculated volume of water taken into storage for each project is also the product of the unit yield and the effective drainage area (MPEDA). The results of this calculation are shown in column 6 in Table 3. This method is not realistic because several projects would be charged for storing more than their total storage capacity.

To take into account the actual amount of storage available it is necessary to assess the status of the index reservoir and then apply the same status to all other minor projects. In the hypothetical example, the index reservoir had the capacity to store 80 per cent of its potential storage volume (capacity at FSL) thus all reservoirs are limited to store not more than 80 per cent of their capacities at FSL. The available storage capacity is shown in column 7 in Table 3 and the volume taken into storage using the available capacity and the total runoff as limiting factors is shown in column 8.

Using equation 1 unadjusted must be rejected since the apparent volumes of water stored do not conform in any consistent way with the amount of storage available.

When compared with the results from the existing method it can be seen that storages calculated using equation 1 adjusted for available storage and runoff volume tend to be lower for minor projects with small effective drainage areas and the same for those with large effective drainage areas. This observation reflects the tendency for a reservoir with a large effective drainage area to fill in dry years, while the same sized reservoir with a small effective drainage area will not. The effect can be seen by comparing projects 3 and 4 in Table 3. These reservoirs have the same capacities at FSL with number 4 having an effective drainage area 15 times larger than number 3.

Assuming that the areas produce the same yield of water per unit area, it would be expected that project 4 would store more water than project 3. Use of the adjusted equation 1 confirms this expectation, while the existing method indicates that the projects would store the same amounts of water.

This inclusion of effective drainage area, combined with the more detailed calculations inherent in the use of equation 1 (i.e. individual minor project storage is calculated) should produce a more precise calculation of minor project storage. A small computer program would be a useful aid in computing the minor project storages with this equation.

Chapter III

CONCLUSIONS

1. The total minor project storage capacity in the Qu'Appelle basin is about 17 per cent of the mean annual natural flow in the basin, as determined at Welby. Therefore, it is important that minor project storage be calculated as accurately as possible.
2. The index reservoir method can provide a reasonable estimate of minor project storage. An equation which uses a ratio of reservoir storage to effective drainage area for both the index reservoirs and the minor projects in the basin offers a logical means of calculating the water taken into storage in minor projects. Adjustments to the apparent volume of water taken into storage, to account for actual storage available and the volume of runoff, increase the accuracy of the calculations of water taken into storage.
3. An index reservoir at Silton cannot be expected to accurately represent runoff in the lower Qu'Appelle. The accuracy of calculations for minor project storage for this part of the Qu'Appelle basin would be significantly improved if an index reservoir was established in the Kaposvar Creek basin.
4. The existing method of calculating minor project storage over estimates the volume of water stored in the minor projects.

Chapter IV

RECOMMENDATIONS

It is recommended that:

1. Index reservoirs continue to be used to estimate small project storage in the Qu'Appelle basin.

2. An index reservoir be established in the Kaposvar Creek basin to replace the Esterhazy Index Reservoir.

3. The effective drainage area of each minor project reservoir and index reservoir in the basin be determined.

4. Minor project storages in each sub-basin be computed using the equation:

Equation 1: $$SMP_k = \frac{IRS_k}{IREDA_k} \times MPEDA_k$$

where SMP_k = total minor project storage in sub-basin "k" - $m^3 \times 10^3$

IRS_k = volume of water stored in the index reservoir of sub-basin "k" during the year - $m^3 \times 10^3$

$IREDA_k$ = effective drainage area contributing to the index reservoir sub-basin "k" - km^2

$MPEDA_k$ = total effective drainage area contributing to all minor project storage reservoirs in the sub-basin "k" - km^2

5. The computed sub-basin storages be limited by the storage available in the index reservoirs. This should be equal to the storage volume available to capture runoff in the index reservoir as a percentage of the index reservoir volume at FSL.