AN EVALUATION OF APPORTIONMENT

MONITORING NETWORKS

for the

SASKATCHEWAN RIVER

at the

SASKATCHEWAN-MANITOBA BOUNDARY

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1. INTRODUCTION

Apportionment balance computation for the Saskatchewan River at the Saskatchewan-Manitoba boundary has been conducted annually since 1973 using a procedure described in a PPWB report entitled “Natural Flow Saskatchewan River at the Saskatchewan-Manitoba Boundary” (PPWB Report No. 45). This procedure requires flow and/or water level records from nine hydrometric gauging stations and two pumping stations. The procedure also requires meteorological data from three meteorological stations. Table 1 shows the gauging stations required for computing apportionment balance at the Saskatchewan-Manitoba boundary.

Two of the nine hydrometric gauging stations currently being used for the apportionment of the Saskatchewan River are also needed for other purposes. The Carrot River near Turnberry station (05KH007) is needed for interprovincial water quality monitoring, while the Elbow Diversion Canal at Drop Structure station (05JG006) is needed for the apportionment of the Qu’Appelle River.

Saskatchewan River basin (see Figure 1) is one of the major river basins in the prairie provinces where monitoring of apportionment is currently required by the Board. Apportionment balance results for this river at the Saskatchewan-Manitoba boundary have been published in the PPWB annual reports. The results show that Manitoba had received its entitlement every year in the past 22 years (1973 to 1994).

In recent years, because of budget restraints, Environment Canada has indicated difficulties in continuing to maintain apportionment monitoring networks at the existing level. The Board, at its March 1994 meeting, approved a COH report entitled “Hydrometric Monitoring Strategy” (PPWB Report No. 127), and directed the COH to review the existing apportionment monitoring networks on interprovincial streams. As part of this review, the Committee on Hydrology at its January 1995 meeting, agreed that the Saskatchewan River’s apportionment monitoring network be evaluated. This report is a summary of that evaluation.

TABLE 1
LIST OF STATIONS INVOLVED IN THE COMPUTATION OF
MONTHLY APPORTIONMENT FLOW OF THE SASKATCHEWAN RIVER
AT THE SASKATCHEWAN-MANITOBA BOUNDARY

Station ID	Station Name	Operating Agencies
05HF007	Broderick Irrigation Project Main Canal below Pumping Station	Sask Water
05KH007	Carrot River near Turnberry	Environment Canada
05KH011	Dragline Channel near Squaw Rapids	Environment Canada
05JG006	Elbow Diversion Canal at Drop Structure	Environment Canada
05HF003	Lake Diefenbaker at Gardiner Dam	Environment Canada
05HD033	Reid Lake near Duncairn	Environment Canada
05KJ001	Saskatchewan River at The Pas	Environment Canada
05HD034	Swift Current Canal at Swift Current	Environment Canada
05KD004	Tobin Lake at Squaw Rapids Spillway	Environment Canada

METEOROLOGICAL DATA REQUIRED

1. Lake Diefenbaker - Monthly gross evaporation and precipitation.
2. Tobin Lake - Monthly gross evaporation and precipitation.
3. Reid Lake - Monthly gross evaporation and precipitation (Gross evaporation for Reid Lake is estimated by multiplying lake Diefenbaker evaporation by 1.10).

ADDITIONAL DATA REQUIRED

1. Luck Lake Irrigation Project Annual Pumpage.
2. Riverhurst Irrigation Project Annual Pumpage.

2. APPORTIONMENT FLOW

Article 3, Schedule B of the Master Agreement On Apportionment defines Manitoba's share of flow for streams crossing the Saskatchewan-Manitoba boundary as :

Natural Flow at the Saskatchewan-Manitoba Boundary minus :

a) one-half the water flowing into Saskatchewan in that watercourse from Alberta,

b) any water which would form part of the natural flow in that watercourse but does not flow into Saskatchewan because of the implementation of any provision of any subsisting water apportionment agreement made between Alberta and Saskatchewan and approved by Manitoba, and

c) one-half the natural flow arising in Saskatchewan.

Saskatchewan River is a typical case that applies to the above formula, because it cross both the Alberta-Saskatchewan and the Saskatchewan-Manitoba boundaries. To determine Manitoba's share of flow, it requires natural flow at the Saskatchewan-Manitoba boundary, recorded flow at the Alberta-Saskatchewan boundary (ie.,Article 3a), consumptive use in Alberta portion of the basin (ie.,Article 3b), and natural flow arising in the Saskatchewan portion of the basin (ie., Article 3c). It is quite clear that Manitoba's share of flow is not simply one-half of the natural flow at the boundary. To avoid possible confusion, a term"Apportionment Flow" has been used in the Saskatchewan River's apportionment computation to simplify the procedure of determining whether Manitoba has received its share of flow from Saskatchewan.

The term "Apportionment Flow" is defined as flow that is subject to apportionment. In the case of the South Saskatchewan River or the Qu'Appelle River, the apportionment flow is equal to natural flow because natural flow at the boundary is subject to apportionment. While in the case of the Saskatchewan River, natural flow at the boundary is not subject to a 50:50 apportionment between Saskatchewan and Manitoba. The share of flow that Manitoba or Saskatchewan is entitled to is not one-half of the natural flow.
Based on the definition stated above, Manitoba's share of flow on the Saskatchewan River can be interpreted as one-half of the water flow into Saskatchewan from Alberta plus one-half of the natural flow arising in Saskatchewan. Recognizing that the flow is shared on a 50:50 basis between Saskatchewan and Manitoba, therefore, the flow that is subject to apportionment (Apportionment Flow) would be the water received by Saskatchewan from Alberta plus natural flow arising in the Saskatchewan portion of the basin.

Apportionment flow at the Saskatchewan-Manitoba boundary and its relationship with natural flow at the boundary may be described mathematically as follows:

Determine Manitoba's share based on Article 3, Schedule B

SHARE man = NF s/m - (½)RF a/s -USE alta - (½)NF sask ....(1)
Where :
SHARE man is Manitoba's share of flow.
NF s/m is natural flow at the Saskatchewan-Manitoba boundary.
RF a/s is recorded flow at the Alberta-Saskatchewan boundary.
USE alta is consumptive use in Alberta portion of the basin.
NF sask is natural flow arising in Saskatchewan portion of the basin.

Assuming no channel loss in the river system, then
NF s/m = NF a/s + NF sask...(2)
Where :
NF a/s is natural flow at the Alberta-Saskatchewan boundary.
Since NF a/s = RF a/s + USE alta, therefore,
NF s/m = (RF a/s + USE alta) + NF sask..(3)

Substitute Eqn(3) into (1)
SHARE man = (RF a/s + USE alta + NF sask) - (½)RF a/s
- USE alta - (½) NF sask..(4)
or SHARE man = (½)RF a/s + (½)NF sask..(5)

Manitoba and Saskatchewan share the flow on a 50:50 basis, therefore, the flow that is subject to apportionment (Apportionment Flow) can be expressed as :

AF s/m = 2 (SHARE man)
or AF s/m = RF a/s + NF sask ....(6)
Where :
AF s/m is apportionment flow at the Saskatchewan-Manitoba boundary.

To eliminate the process of estimating natural flow arising in the Saskatchewan portion of the basin, apportionment flow at the Saskatchewan-Manitoba boundary can also be expressed, by applying the concept of Project Depletion Method, as follows:

AF s/m = RF s/m + USE sask(7)
Where :
USE sask is consumptive use in Saskatchewan portion of the basin.

The existing computational procedures were developed based on the above concept. Apportionment flow at the Saskatchewan-Manitoba boundary is calculated by routing major water use items to the Saskatchewan-Manitoba boundary. The routed water use items are then added to the flow at the boundary to arrive at the apportionment flow. Because there is no gauging station at the boundary, flow at the boundary is computed by subtracting local inflows in Manitoba from the recorded flow at The Pas. The local inflows are computed by multiplying the recorded flow for Carrot River near Turnberry by a factor of 1.31.

3. WATER USE PROJECTS IN SASKATCHEWAN

Water rights information for projects licenced by Saskatchewan provide a general idea about the magnitude of water that may be diverted from the basin for a variety of purposes, such as domestic, municipal, irrigation, industrial, etc. The diversion figure shown on a licence, however, in most cases, does not reflect to the net depletion of a project. For example, a great portion of diversion in the Saskatchewan River is for hydroelectric power generation purposes (eg., project No. 07592 has a licenced diversion of 427 108 dam^3). Most of the water diverted for such purposes is returned to the river and does not actually consume water from the river.

Table 2 shows a summary of water use projects in the Saskatchewan portion of the basin. A total of 3 774 projects are currently licenced by Saskatchewan with an annual diversion of 1 312 648 dam^3 . It is interested to point out that annual diversion for industrial purposes (eg., hydroelectric) is 561 553 dam^3 that accounts for 42.8% of the annual diversion in the basin.

Normally, the annual diversion shown on the licence is the maximum amount of water that is permitted for consumption. Applying the diversion figures to the apportionment computation would tend to over estimate water use in the basin. Moreover, a significant number of projects are situated outside the effective drainage area of the basin, and it is likely that water diverted from such area has little or no effect on the apportionment flow at the boundary.

Given the number of water use projects in the basin, it would be impractical to monitor every singer project in the basin. The existing apportionment flow computational procedures take into account eleven major water use items which represent major net depletion in the Saskatchewan portion of the basin. Water use for major urban centres such as Saskatoon and Prince Albert are not considered in the existing apportionment flow computation because the net depletion for these two cities are relatively insignificant when compared with annual apportionment flow at the boundary. Water intake for the City of Saskatoon is about 42 000 dam^3 a year. Assuming 70% of the flow is returned to the river, the net consumption is about 12 600 dam^3 which is equivalent to 0.07% of the average apportionment flow. Similarly, for the City of Prince Albert, annual net water consumption is only about 0.02% of the average apportionment flow.

TABLE 2
WATER RIGHTS PROJECTS IN THE SASKATCHEWAN PORTION
OF THE SASKATCHEWAN RIVER BASIN

TYPE OF USE	NUMBER OF PROJECT	DIVERSION ($Dam^{3)}$	% OF DIVERSION
DOMESTIC	1877	**9205**	0.7
INDUSTRIAL	42	561553	42.8
IRRIGATION	1500	257012	19.6
MULTIPLE	17	139474	10.6
MUNICIPAL	129	215660	16.4
OTHERS	209	129744	9.9
TOTALS	3774	1312648	100

** Data Courtesy of Sask Water.

There are many other water use projects in the Saskatchewan portion of the Saskatchewan River basin having less than one percent of an effect on annual apportionment flow at the boundary. Most of the water diverted for domestic, and municipal purposes are ignored in the existing apportionment computation. A concern may be raised about the accumulative effects that such projects have on the accuracy of annual apportionment flow. At present, total net consumption for such usage is still not a significant item when compared to the average annual apportionment flow at the boundary. Practically, it would be more cost-effective to ignore such use in the apportionment computation until some time in the future when any of these usage becomes significant.

Appendix A lists the computed annual water uses for each of the eleven water use items considered in the current computational procedures. The volumes shown have been routed from the project site to the border. It shows that annual water use for these water use items account for a relatively small portion of the annual apportionment flow. Mean annual water use is 601 879 dam^3 which is about 3.5% of the mean annual apportionment flow. The percentage ranges from a minimum of -3.85% in 1981-82 to a maximum of 9.31% in 1992-93

A review of the annual water balance in Appendix A shows that seven of the eleven water use items had annual uses that never exceeded one percent of the annual apportionment flow over the 21-year period from 1973-74 to 1993-94. The seven water use items are:

1. Reid Lake Net Evaporation (Maximum effect of 0.09% in 1988-89).

2. Swift Current Irrigation Project (maximum effect of 0.20% in 1987-88).

3. Reid Lake Change in Storage (Maximum effect of 0.23% in 1982-83).

4. Luck Lake and Riverhurst Irrigation Projects (Maximum effect of 0.24% in 1992-93).

5. Tobin Lake Net Evaporation (Maximum effect of 0.70% in 1984-85).

6. Dragline Channel (Maximum effect of 0.80% in 1989-90).

7. Broderick Irrigation Project (Maximum effect of 0.99% in 1984-85).

Among the seven water use items listed above, "Luck Lake and Riverhurst Irrigation Projects" require pumpage information from two pumping stations currently operated by Sask Water. "Broderick Irrigation Project" requires monthly flow records from gauging station "Broderick Irrigation Project Main Canal below Pumping Station" which is presently operated by Sask Water for water management purposes. Water use item "Tobin Lake net evaporation" requires water level information from gauging station "Tobin Lake at Squaw Rapids Spillway". The same information is also needed for computing Tobin Lake's change in storage. The remaining four water use items (two of which pertain to the same hydrometric gauging station) require hydrometric information from three gauging stations currently operated by Environment Canada.

Table 3 lists the variation and magnitude of annual water use for each of the eleven water use items used in the existing computational procedures. It shows the effect of each water use item to the annual apportionment flow. It also provides the statistical information to show the level of importance of each water use item. Judging from the importance of each water use item, and the gauging stations required for each water use item, six gauging stations are considered of less importance and that flow or water level data normally measured at these stations may be estimated rather than actually monitored. These six stations are :

1. Swift Current Canal at Swift Current (05HD034).
2. Reid Lake near Duncairn (05HD033).
3. Dragline Channel near Squaw Rapids (05KH011).
4. Broderick Irrigation Project Main Canal below Pumping Station (05HF007).

5. Luck Lake Irrigation Project Pumping Station.
6. Riverhurst Irrigation Project Pumping Station.

Alternative methods for estimating flow or water level at these stations are discussed in the following section.

TABLE 3
VARIATION OF WATER USE ITEMS IN THE
SASKATCHEWAN PORTION OF THE
SASKATCHEWAN RIVER BASIN
(UNIT : DAM^3)

4. ALTERNATIVE METHODS FOR ESTIMATING FLOW OR WATER LEVEL AT A SITE

Recent budget restraints in Environment Canada has raised the need of reviewing the existing monitoring network to see if any of the monitoring stations can be discontinued or to identify ways to operate the existing network more effectively. At the present level of development, six of the existing gauging stations are considered of less importance in terms of their effect on the accuracy of annual apportionment flow. It may be feasible to estimate the flow for these stations, thereby, permitting the discontinuation of these gauging stations.

There are several approaches that may be used to estimate flow data at a gauging station site. Regression analysis is one of the approaches frequently used. It utilizes historical records at the site and stations in the adjacent area to develop a regression equation which is then used to estimate flow data at a site. This approach is suitable for estimating streamflow for stations that have the similar hydrological characteristics. Its application to the Saskatchewan River apportionment monitoring network is questionable because most of the gauging stations that are considered for possible discontinuation are primarily related to the monitoring of regulated flow (eg. canal flow, pumpage) rather than natural runoff. With the current trend of budget restraint, it is not certain that adjacent stations selected for regression purposes will continue to be maintained. Moreover, any stations that are selected for regression purposes, would be classified as PPWB stations, and it may end up with increasing rather than decreasing the number of PPWB stations.

One other way to estimate flow records at a site is to use the water rights data. Instead of monitoring diversion at a site, it assumes the diversion is the same as that specified on the licence. Applying this approach to the case of Saskatchewan River would have the tendency of over estimating the diversion at a site, because the diversion specified on the licence normally exceeds the actual consumption of a project.

Since most of the gauging stations used in the existing apportionment computational procedures have been operated for a relatively long period of time, it would be possible to estimate the data based on the historical records. One simple way of estimating monthly flow at a designated gauging station is to use historical mean monthly flow. Applying mean monthly values may not be as accurate as those based on measurement at a site, but it should serve the intended purpose. Table 4 shows the mean monthly flow (or water level) that may be applied for the six designated gauging stations.

TABLE 4
MEAN FLOW OR WATER LEVEL
USED IN THE SENSITIVITY ANALYSIS

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC

SWIFT CURRENT CANAL AT SWIFT CURRENT. (05HD034) (m^3/sec)

0.00	0.09	0.263	1.14	1.08	0.509	0.835	0.457	0.16	0.105	0.387	0.00

REID LAKE NEAR DUNCAIRN. (05HD033) (water level in metre minus 800)

4.658	4.69	5.222	6.095	6.034	5.786	5.562	5.052	4.841	4.726	4.692	4.757

DRAGLINE CHANNEL NEAR SQUAW RAPIDS. (05KH011) (m^3/sec)

0.683	0.601	0.59	0.701	1.47	2.53	3.62	3.16	2.44	1.66	0.466	0.734

BRODERICK IRRIGATION PROJECT MAIN CANAL BELOW PUMPING STATION. (05HF007) (m^3/sec)

0	0	0	0.286	4.1	5.93	8.4	5.71	3.2	0.456	1.95	0.00

LUCK LAKE AND RIVERHURST IRRIGATION PROJECT PUMPING STATIONS. (m^3/sec)

0	0	0	0	1.965	2.032	1.965	1.965	0	0	0	0.00

5 . SENSITIVITY ANALYSIS

To assess the effects of discontinuing any or all of the stations at which the flow or water level records has less than one percent of effect on the annual apportionment flow, six specific scenarios were considered. They pertained to the discontinuation of :

1. Swift Current Canal at Swift Current (05HD034). Environment Canada station.

2. Reid Lake near Duncairn (05HD033). Environment Canada station.

3. Dragline Channel near Squaw Rapids (05KH011). Environment Canada station.

4. Broderick Irrigation Project Main Canal below Pumping Station (05HF007). Sask Water station.

5. Luck Lake and Riverhurst Irrigation Project Pumping Stations. Sask Water stations.

6. All of the above hydrometric and pumping stations.

Annual apportionment flow volumes for each scenario was computed using the long-term mean monthly flow (or water level) to replace the actual records. For example, for scenario 1, mean monthly flow records for Swift Current Canal at Swift Current were used in the input data file. Table 5 shows the results of apportionment flow for each scenario. It appears that the difference between the apportionment flow computed using the existing monitoring networks and those computed based on the selected scenarios is relatively small. In all of the scenarios considered, the differences are all less than one percent. Figures 2 to 7 provide comparisons of annual apportionment flow computed based on existing network versus those computed based on selected scenarios. It appears that the difference are relatively small for all scenarios.

Table 6 shows the magnitude of the effects if monitoring at all six stations (four hydrometric stations and two pumping stations) were discontinued. With the approach of using the mean monthly flow (or water level) in the computation, the effect would range from - 0.81% to 0.67% with a mean effect of - 0.09% as compare to the approach of ignoring flows at all these stations (ie., assuming all flow are zero and all water levels are constant) which would have an effect ranging from +0.16 to 2.16% with a mean effect of 0.92%. This analysis proves that the approach of using mean monthly flow records in the apportionment flow computation is an adequate method for practical application.

TABLE 5
A COMPARISON OF APPORTIONMENT FLOW VOLUMES
FOR SELECTED NETWORK SCENARIOS
(UNIT : DAM^3)

TABLE 6
POSSIBLE EFFECTS OF TERMINATING THE SELECTED GAUGING STATIONS

6. CONCLUSIONS

1. The term “Apportionment Flow” is adequate for use in the apportionment balance computation for the Saskatchewan River to determine if the term of the Master Agreement is met.

2. There are 3774 licenced projects in the Saskatchewan Portion of the Saskatchewan River basin with a total annual diversion of 1 312 648 dam^3. Licenced diversion for industrial purposes is 561 553 dam^3 , 42.8% of the annual licenced diversion in the basin. Most of the industrial diversion are for hydropower generation purposes and their net effect on the annual apportionment flow is minimal.

3. Annual water use in the Saskatchewan portion of the Saskatchewan River basin varies from year to year from a high of 1 575 045 dam^3 to a low of - 686 950 dam^3. The percentage of annual water use to annual apportionment flow at the Saskatchewan-Manitoba boundary ranges from a low of - 3.85% in 1981-82 to a high of 9.31% in 1992-93.

4. The 11 water use items considered in the existing computational procedures represents most of the net depletion in the Saskatchewan portion of the Saskatchewan River basin.

5. Seven of the eleven water use items currently considered in the apportionment calculation had annual uses that never exceeded one percent of the annual apportionment flow over the 21-year period from 1973-74 to 1993-94. These seven water use items are presently monitored by four hydrometric and two pumping stations.

6. The impact of discontinuing four hydrometric and two pumping stations currently used in the apportionment computation would be acceptable if mean monthly values for these stations were used in the computation process.

7. Three of the gauging stations identified for possible discontinuation are currently operated by Sask Water for water management purposes. It would be up to Sask Water to decide whether these stations should be discontinued.

7. RECOMMENDATIONS

It is recommended that:

1. The existing procedures for computing the apportionment balance of the Saskatchewan River should continue be used.

2. Five of the existing hydrometric gauging stations, each playing an important role in monitoring the apportionment, should remain in operation. These five stations are:

   - Carrot River near Turnberry (05KH007)
     (This station is also needed for water quality monitoring purposes)

   - Elbow Diversion Canal at Drop Structure (05JG006) (This station is also needed for apportionment monitoring of the Qu'Appelle River)

   - Lake Diefenbaker at Gardiner Dam (05HF003)

   - Saskatchewan River At The Pas (05KH001)

   - Tobin Lake at Squaw Rapids Spillway (05KD004)

3. The following three hydrometric gauging stations, currently operated by Environment Canada, be removed from the PPWB hydrometric monitoring stations list:

   - Swift Current Canal at Swift Current (05HD034).
   - Reid Lake near Duncairn (05HD033).
   - Dragline Channel near Squaw Rapids (05KH011).

   Mean monthly flow (or water level) of these stations should be used in future computations of apportionment balance.

4. Flow records for the following three Sask Water stations should continue be used in the apportionment computation:
   - Broderick Irrigation Project Main Canal below Pumping Station (05HF007)
   - Luck Lake Pumping Station
   - Riverhurst Pumping Station .

   In the event that flow records are not available from Sask Water, mean monthly flow should be used in the computation.

APPENDIX A

SUMMARY OF WATER USE ITEMS IN SASKATCHEWAN PORTION OF THE SASKATCHEWAN RIVER BASIN