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DEPARTMENT OF TRANSPORT
METEOROLOGICAL BRANCH

THE ESTIMATION OF THE WATER SURFACE TEMPERATURE FOR TWO PRAIRIE RESERVOIRS

BY

A.C. WANKIEWICZ

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315 Bloor Street, West,
Toronto 5, Ontario.

THE ESTIMATION OF THE WATER SURFACE TEMPERATURE FOR TWO PRAIRIE RESERVOIRS

by

A. C. Wankiewicz*

ABSTRACT

The weekly averages of air and water surface temperature, solar radiation, wind and changes in water levels were studied for Weyburn and Morden Reservoirs to obtain relationships which were useful in the estimation of water surface mean temperature. Estimates are required for the computation of evaporation for water supply studies. Regression equations of the form:-

$$Tw = a(Ta) + b(\Delta Ta) + c,$$

where

Tw = weekly mean water surface temperature,

ta = weekly mean air temperature,

Δ Ta = increment in Ta from the previous to present week,

gave the most satisfactory results. Using these equations it was possible to estimate water surface mean temperatures with the following accuracy:-

	STANDARD ERROR OF ESTIMATE °F			
	Weekly Estimate	n	Monthly Estimate	n
Morden Reservoir	3.3	22	-	4
Weyburn Reservoir	2.0	53	1.4	14

* This study was undertaken while Mr. Wankiewicz, a second year honours physics undergraduate of the University of Alberta, was employed as a Student Assistant with the Meteorological Service of Canada during the summer of 1964.

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315 Bloor Street, West,
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L'ESTIMATION DE LA TEMPERATURE DE L'EAU DE SURFACE POUR DEUX RESERVOIRS DES PRAIRIES

par

A. C. Wankiewicz

RÉSUMÉ

Les moyennes hebdomadaires de la température de l'air et de la surface de l'eau, du rayonnement solaire, du vent et des variations du niveau des eaux ont été étudiées pour les réservoirs Weyburn et Morden afin d'obtenir des relations qui ont servi à l'estimation de la température moyenne de la surface de l'eau. Des estimations sont nécessaires au calcul de l'évaporation dans les études d'approvisionnement d'eau. Des équations régressives de la forme:

$$Tw = a(Ta) + b(\Delta Ta) + c$$

dans lesquelles

Tw = température moyenne hebdomadaire de la surface de l'eau,

ta = température moyenne hebdomadaire de l'air,

Δ Ta = accroissement de Ta de la semaine précédente à la présente semaine,

ont donné les résultats les plus satisfaisants. Il a été possible au moyen de ces équations d'estimer les températures moyennes de la surface de l'eau avec la précision suivante:

	ERREUR NORMALE DE L'ESTIMATION EN °F			
	Estimation hebdomadaire	n	Estimation mensuelle	n
Réservoir Morden	3.3	22	-	4
Réservoir Weyburn	2.0	53	1.4	14

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1. INTRODUCTION

Water surface temperature is used by the hydrologist to estimate evaporation. It also has wide application in the fields of physical and biological limnology. In the estimation of evaporation, water temperature is used to compute the vapour pressure of the air at the water surface, a term used in the aerodynamic-type formulae.

Records of water temperature for Western Canada are few and fragmentary. Consequently, if aerodynamic formulae are to be used, water temperatures must generally be estimated. One common practice for very small reservoirs is to assume that the monthly mean air and water temperature are equal. The use of this or other general approximations may lead to significant inaccuracies for as McKay and Stichling (1) point out, a bias of one degree F may cause an error of about 5 per cent in computed evaporation (based on the Meyer formula). Since evaporation extracts an average of three feet of water annually from prairie reservoirs (2), this 5 per cent error may represent a substantial quantity of water.

The purpose of this report is to provide a method of estimating water surface temperature from commonly available meteorological parameters such as air temperature, winds and bright sunshine. These parameters and the water temperature were measured during the ice-free period at Weyburn Reservoir in connection with an evaporation study initiated in August 1960. Records are also available from Morden Reservoir from 1963 to date.

The subsequent pages outline the problem and analysis. A statement of the problem is followed by a description of the reservoirs and the local climate. The data and the importance of each variable in an estimation scheme are then discussed. Since air temperature was found to be the best single predidtor, its role, and the utility of the regression equations are assessed.

2. HISTORY

The only lake in the vicinity of the Canadian prairies with a continuous long record (50 years) of the water temperature is Lake-of-the-Woods. However, this lake is non-typical of prairie reservoirs, both in its large size of 950,000 acres and in its local topography and climate. Berry and Stichling (3) have correlated the monthly mean water temperature of the lake

with the air temperatures of preceding months. They suggest that, "Very small bodies of water will remain close to air temperatures: the larger the lake, the more the water temperature will lag the air temperature due to heat storage" (4). The latter part of this quote is substantiated by records from Lakes Winnipeg; Pasquia, 5000 acres; and Lake-of-the Woods (5). Meyer concludes from his study of American lakes (6) that a northern lake's water temperature averages somewhat higher than the air temperature during the open season.

3. THE RESERVOIRS

The reservoir at Weyburn, 70 miles southeast of Regina, is in slightly rolling prairie country. A report by McKay (7) describes the climate of the area and establishes that it is representative of a broad region. The reservoir is aligned with the prevailing northwest and southeast winds and is offered little protection in the form of trees or marshy areas.

Morden reservoir (Lake Minnewasta) in southern Manitoba, is somewhat better protected than Weyburn by local topography and vegetation. Its characteristics and those of Weyburn are shown in Table I.

TABLE I

RESERVOIR CHARACTERISTICS

	RESERVOIR	
	WEYBURN	MORDEN
Latitude.....	49°40'	49°11'
Capacity.....(acre-feet).	4890	2100
Area when full (acres).....	570	134
Average depth (feet).....	8.5	16
Apr-Oct. average -		
Air temperature (°F).....	56	57
30' winds (m.p.h.).....	10	-
Average annual		
Precipitation (inches).....	16	20

The seasonal variation of air temperature, insolation, and winds for Weyburn are shown in Fig. 1.

4. DATA

The records used in this analysis cover the following periods:-

TABLE II

WEYBURN RESERVOIR		
	1960	Aug 4-Sep 30
	1961	Apr 28-Oct 16
	1962	May 3-Aug 31
		Sep 14-25
	1963	Jul 1-Sep 30
	1964	May 5-Jun 1
MORDEN RESERVOIR		
	1963	Jun 12-Jul 30
		Aug 6-Sep 26
	1964	May 15-Aug 3

The parameters recorded at Weyburn are:-

Water Surface Temperature

In the years 1960-62, the maximum and minimum temperatures at one- and twelve-inch depths were recorded every two or three days from a raft located in 18 feet of water. Temperature-time graphs were then constructed using these values and reconstructed values computed from the maximum and minimum daily air temperatures. A Bristol 500 (double sensor) temperature recorder was operating by July 1, 1963. This provided a continuous record of the surface temperature. The abstracted temperatures, twelve per day, were then averaged to give a weekly mean.

Insolation

The unit of insolation used in this report is the langley per week (calorie per cm^2 per week). To calculate this, a graph was prepared which compared Swift Current computed versus measured insolation - the computed insolation being deduced from a nomogram developed by Hamon, Weiss, and Wilson (8). Weyburn insolation was computed from the graph, by using Weyburn bright sunshine records.

Air Temperature

The weekly average air temperatures were obtained from daily maximum and minimum readings for a location five miles northwest of the raft.

Wind

The parameter investigated was the weekly mean wind.

Stage

The level or stage of the lake was measured with a Leupold-Stevens A-35 stage recorder.

The parameters from Morden Reservoir, which were used in this study, are the air and water temperatures. The water surface temperatures were measured using a Bristol 500 recorder. The sensors were located on a buoy in 25 feet of water. The air temperatures were averaged from daily readings of the Morden Experimental Station.

5. PROCEDURE AND RESULTS

Measurements of meteorological parameters were compared with water temperature measurements to observe if relationships existed which were useful for the estimation of water temperature. Weekly averages were used since the lag time between air and water temperatures appeared from preliminary inspection to be of this order. It was subsequently found that correlations between air and water temperatures were small where the time separation exceeded one week.

The following is an evaluation of each of the relationships which were investigated.

Insolation

The relationship between water temperature and insolation is shown in Fig. 2. That this is not a simple one is made evident by the large scatter. Consequently, any estimate based on insolation in subsequently tested multiple regression equations did not significantly improve their value for prediction.

Air Temperature

The correlation between water and air temperature is indicated in Figs. 3 and 4. Both Weyburn and Morden Reservoirs have water temperatures which average higher than the air temperatures. In fact, the mean differences are 2.7°F and 3.2°F for Weyburn and Morden respectively. The seasonal variations in these values are shown in Table III.

TABLE III

MONTH	WEEKLY AVERAGE WATER MINUS AIR TEMPERATURE (°F)			
	WEYBURN		MORDEN	
	No. of cases	Difference	No. of cases	Difference
MAY	11	3.0	2	2.6
JUN	12	2.5	6	1.6
JUL	12	3.7	8	3.4
AUG	14	2.5	3	4.7
SEP	10	2.6	3	5.2

The potential accuracy of a forecast based on the air temperature is indicated in Fig. 5. A regression equation on the 13 weeks of 1963 ($Tw = 0.985\ Ta + 3.8$), Weyburn Reservoir, has a correlation coefficient of .93. The standard error of estimating the 1963 Weyburn water temperatures (weekly means) is 2.0°F.

This equation, however, indicates the temperature of the lake best when conditions are not changing rapidly. With rapidly changing conditions the high energy-storage-capacity of water will result in a prediction error. Because of the high correlation between weekly air and water temperature, compensation for this error may be made by introducing the previous week's air temperature into the regression equation. In Fig. 6, the estimation error using the above regression is plotted against the increase in weekly mean air temperature from the previous week (ΔTa). The estimate tends to be high for a positive change in air temperature and vice-versa. The multiple regression equation between the water and air temperatures and the term (ΔTa), ($Tw = 1.154\ Ta - 0.318\ \Delta Ta - 7.3$ for Weyburn Reservoir, 1963), has a partial correlation coefficient of .98. Using this equation the standard error of estimate for 1963 Weyburn data is 1.2°F, and somewhat higher if other years are included. A regression equation which used air temperatures for the second preceding week as well, failed to improve on this accuracy. It is reasonable, then, to assume that water temperatures may be predicted from air temperature using a multiple regression of the form:-

$$Tw = a(Ta) + b(\Delta Ta) + c.$$

The nature of the experimental constants and the statistical results obtained using this form of an equation for both Morden and Weyburn reservoirs, are shown in Table IV.

TABLE IV

	RESERVOIRS	
	WEYBURN	MORDEN
Average Depth (feet).....	8.5	16
Equation coefficients - a.....	+1.006	+0.910
b.....	-0.298	-0.433
c.....	+2.4	+8.6
Period used.....	1961-1963 (53 weeks)	1963-1964 (22 weeks)
Multiple correlation coefficient.	0.974	0.854
Standard error, °F (weekly mean).	2.0	3.3

As an example of the use of the regression equation for Weyburn, computed for the years 1961-1963, the errors of estimation for independent data for 1964 are shown in Table V.

TABLE V

WEEK	WEYBURN RESERVOIR - 1964		
	ACTUAL WATER TEMPERATURE	ESTIMATE	ERROR
May 6-12	52.5	51.9	-0.6
13-19	59.4	60.0	+0.6
20-26	62.8	63.9	+1.1
May 27-Jun 2	59.7	54.5	-5.2
Jun 3-9	62.1	58.8	-3.3
10-16	61.5	60.1	-1.4
17-23	59.9	60.1	+0.2
24-30	69.3	66.7	-2.6

Standard error of estimate..... 2.6°F.

Fig. 7 shows a seasonal correction to the regression equation for Weyburn Reservoir. It was constructed from the nine-week running means of the forecast error, 1961 to 1964. With this correction, the standard error of estimate of the weekly mean is 1.8°F. Because of the limited amount of Morden data, no seasonal correction was computed.

Winds

The wind may lower the temperature of the water surface in two ways. First, by means of evaporation in accordance with the mass-transfer formula:-

$$E = (a+bu)(ew-ea),$$

where

E = evaporation in inches,

u = wind speed in m.p.h.,

ew = saturation vapor pressure over water surface,

ea = air vapor pressure,

a, b = experimental constants.

Secondly, wind may increase circulation so as to replace the surface waters with the cooler ones below. However, an investigation for an effect of wind speed and/or direction on the water temperature estimate failed to produce any conclusive results.

Stage

The energy storage capacity of a reservoir is proportional to its average depth. It is, therefore, to be expected that stage plays a significant role in determining the water temperature. This is quite apparent when the temperature cycle of large and small lakes is compared.

The seasonal variation of the average depth of Weyburn Reservoir is shown in Fig. 8, while a comparison of stage and error in water temperature estimate is presented as Fig. 9. A relationship between stage and temperature is indicated.

The effect of stage is also implicit in the magnitude of the coefficient b, Table IV, which is larger for the deeper reservoir.

It may be reasoned from the above that the relationship between estimate error and weekly change in mean air temperature (Fig. 6) is also affected by stage. To show this, The data were grouped into three classes of equal population, representing high, medium and low stage. The scatter diagrams comparing estimate error and ΔT are shown as Fig. 10. The effect is evident in graphs 10a and 10b, but is not apparent in the low-water case 10c.

6. THE MONTHLY MEAN ESTIMATE

The preceding sections indicated the usefulness of air temperatures in predicting water temperatures using weekly data. Since monthly values are required in many operations, it is necessary to consider the accuracy which might be obtained in estimating monthly values by this method. For simplicity the monthly mean is accepted here as the simple average of four weekly-mean estimates. A comparison of computed and actual values is given in Table VI.

TABLE VI

MONTH	ACTUAL WATER TEMPERATURE (°F)	ESTIMATE (°F)	ERROR
WEYBURN RESERVOIR (with seasonal correction)			
1961 Apr 29-May 26	51.0	50.7	-0.3
May 27-Jun 23	68.1	69.7	+1.6
Jun 24-Jul 21	70.0	71.4	+1.4
Jul 22-Aug 18	71.2	71.9	+0.7
Aug 19-Sep 15	64.0	65.1	+1.1
Sep 16-Oct 13	47.6	47.8	+0.2
1962 May 13-Jun 9	57.4	56.1	-1.3
Jun 10-Jul 7	69.6	68.6	-1.0
Jul 8-Aug 4	68.8	67.1	-1.7
1963 Jul 1-Jul 28	72.6	71.5	-1.1
Jul 29-Aug 25	71.3	71.3	0.0
Aug 26-Sep 22	63.5	63.4	-0.1
1964 May 6-Jun 2	58.6	58.5	-0.1
Jun 3-Jun 30	63.3	62.0	-1.3
Standard error of estimate (1961-1964) is 1.2°F.			
WITHOUT the seasonal correction the standard error of estimate is 1.4°F.			
MORDEN RESERVOIR (No seasonal correction)			
1963 Jul 1-28	75.6	71.9	-3.7
Aug 12-Sep 8	70.2	69.4	-0.8
1964 Jun 2-Jun 29	60.9	62.2	+1.3
Jun 30-Jul 27	72.2	73.4	+1.2

7. LIMITATIONS IN THE METHOD

Four limitations to this study are apparent. Firstly, the assumption of a reservoir of uniform surface temperature and of a unique air temperature associated with it is not strictly valid. Thermal surveys at Weyburn reveal areal variations of over 1°F in the surface temperature over deep water (9). However, the weekly average of the water temperature appear to be relatively constant over those parts of the reservoir which are not shallow and do not exhibit any exceptional peculiarities (e.g., marshy areas).

Secondly, two different types of water temperature measurements have been used for Weyburn Reservoir. The assumption of homogeneity of data is not correct, as was pointed out in the section on Data. In 1960-1962 the weekly average is based on two to three readings with the intervening days' temperatures reconstructed. However, in 1963 and 1964, 84 readings were averaged each week from the temperature recorder's continuous record.

Thirdly, the neglect of wind, atmospheric vapour pressure and stage limits the accuracy of the method. However, there is insufficient data at this time to properly evaluate these terms.

Finally, the general lack of data does not permit a check of the general applicability of equations of this type to prairie reservoirs.

8. CONCLUSIONS

Air temperature was found to give the most useful prediction of water surface temperature in an investigation of relationships between commonly measured weather parameters and water temperature for Weyburn Reservoir. A regression equation of the form:-

$$Tw = a(Ta)+b(\Delta Ta)+c,$$

where

Tw = weekly mean water temperature,

Ta = weekly mean air temperature,

ΔTa = increase in air temperature from the previous week,

was selected as most practical for prediction. Monthly estimates may be obtained by using the simple average of four weekly-mean estimates. The standard error of estimate for this method was found to be 1.4°F for Weyburn Reservoir.

Similar relationships were obtained for Morden Reservoir, however, the period of record was too short to obtain significant results.

9. ACKNOWLEDGEMENTS

The author is indebted to Mr. G. A. McKay, Hydrometeorologist with Canada Department of Transport, for the many profitable and entertaining discussions which always resulted in new and useful ideas. A sincere thanks is also extended to Mr. L. H. Ruhr of the Prairie Farm Rehabilitation Administration, Canada Department of Agriculture, whose assistance helped to reduce much of the work.

APPROVED,

J. R. H. Noble,
Director.

10. REFERENCES

(1) McKay, G. A. and W. Stichling, 1961: "Evaporation Computations for Prairie Reservoirs," National Research Council, Associate Committee on Geodesy and Geophysics, Second Canadian Hydrology Symposium, Toronto, p. 18.

(2) Ibid., p. 4.

(3) Berry, W. M., and W. Stichling, 1954: "Evaporation from Lakes and Reservoirs in the Northern Plains Region of North America," International Union of Geodesy and Geophysics, General Assembly at Rome, Tome III, pp. 121-134.

(4) Ibid., p. 123.

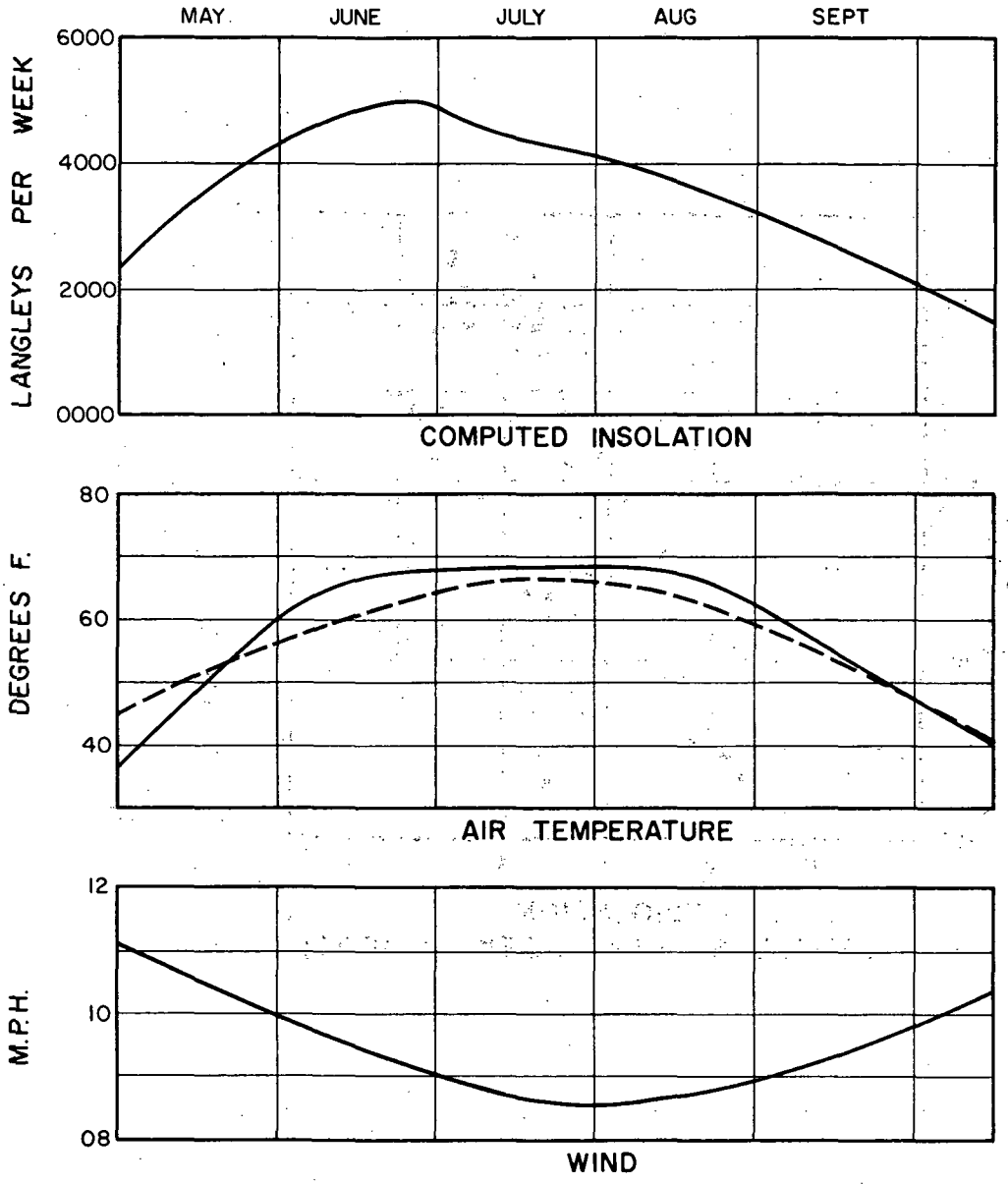
(5) Ibid., Reference 1, Fig. No. 8.

(6) Meyer, A. F., 1942: "Evaporation from Lakes and Reservoirs," Minnesota Resources Commission, St. Paul, Minn., p. 23.

(7) McKay, G. A., 1962: "Evaporation from Prairie Reservoirs - Progress Report 1960-1961," Canada Department of Agriculture, Prairie Farm Rehabilitation Administration, Hydrology Division, 25 pp.

(8) Hamon, R. W., L. L. Weiss, and W. T. Wilson, 1954: "Insolation as an Empirical Function of Daily Sunshine Duration," Monthly Weather Review, Vol. 82, pp. 141-6.

(9) Ibid., Reference 1, Fig. No. 2.



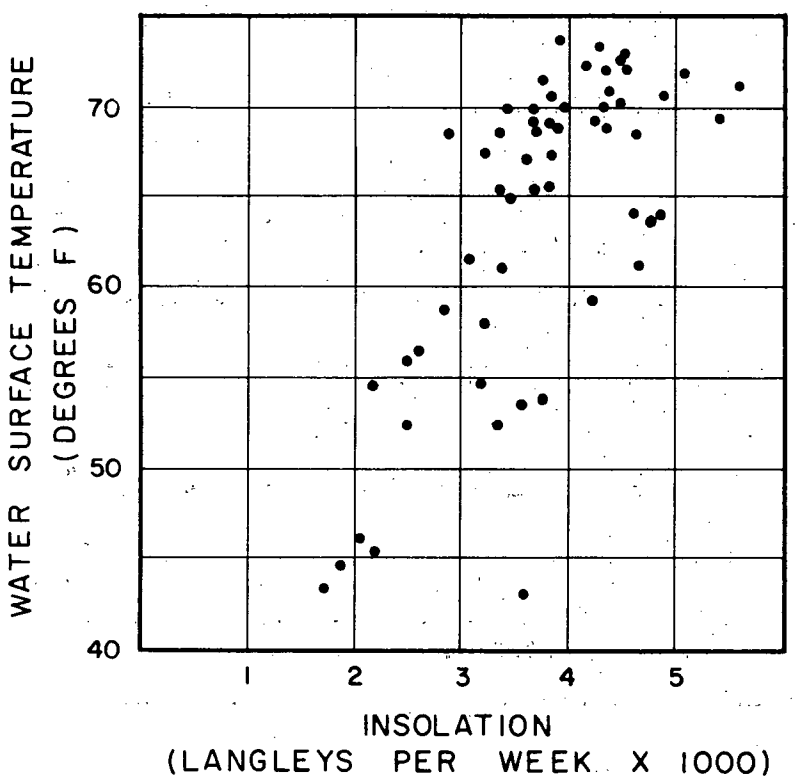
LEGEND

WEYBURN 1961-1964

YELLOW GRASS LONG-TERM AVERAGE

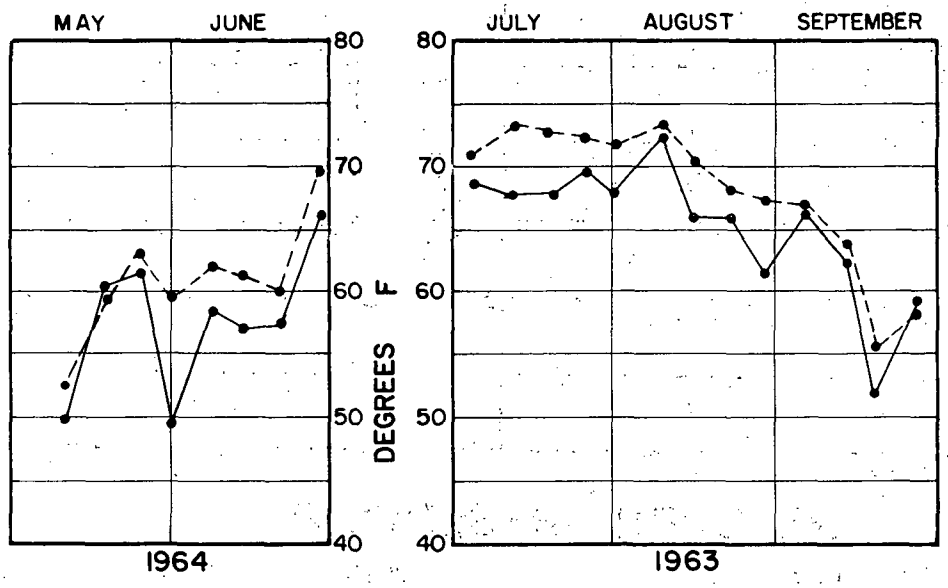
WEYBURN INVESTIGATION
PERIOD AVERAGES
MAY – SEPT

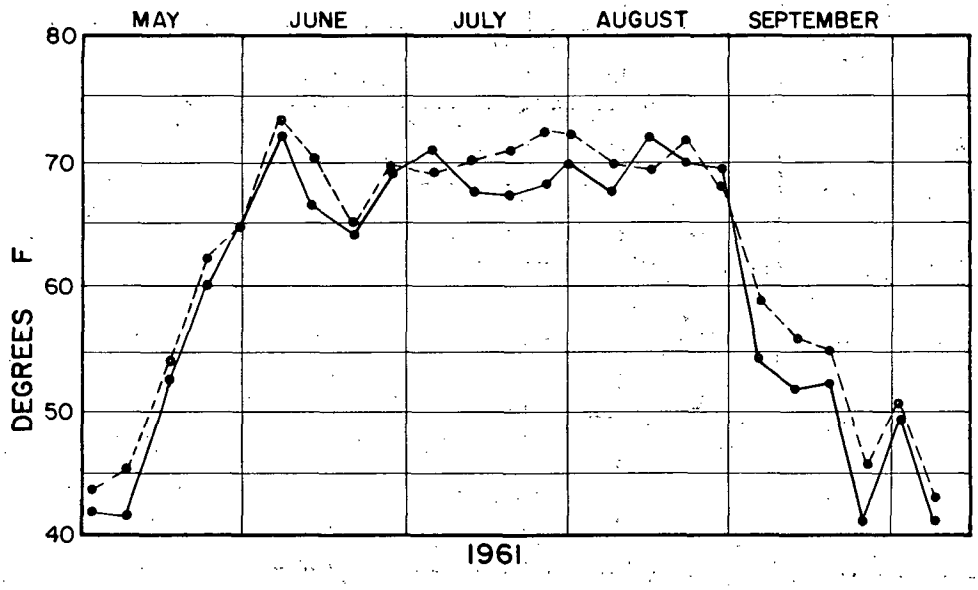
FIGURE – 1



INSOLATION AND WATER TEMPERATURE
WEYBURN RESERVOIR

FIGURE 2





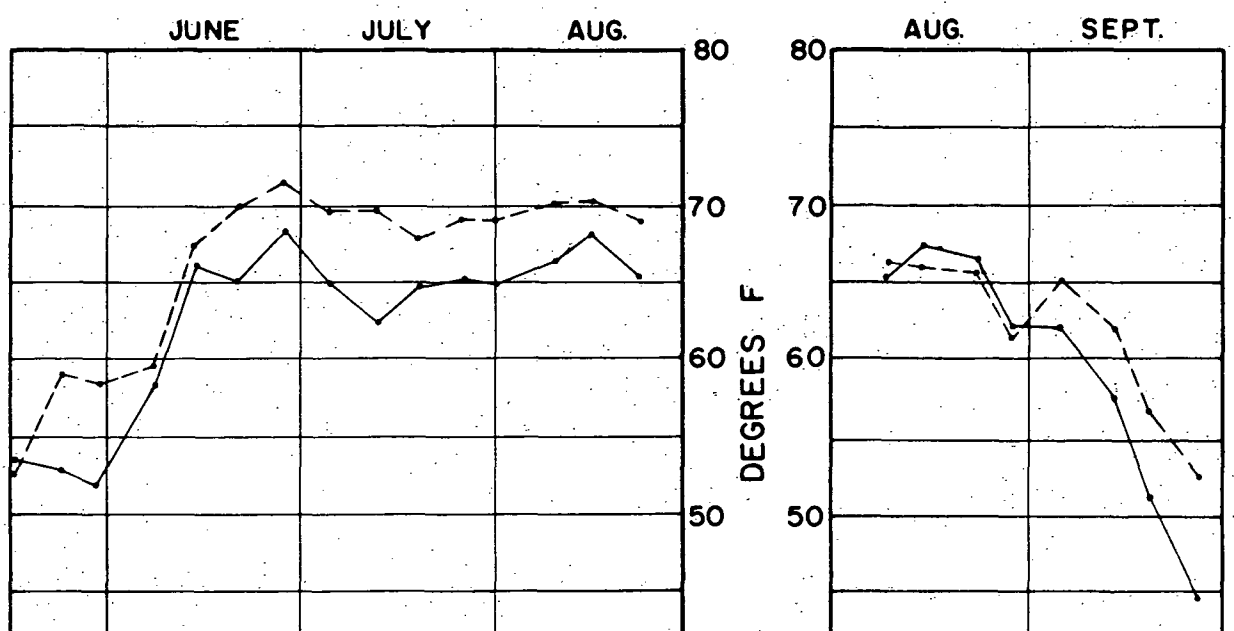
LEGEND

WATER TEMPERATURE.

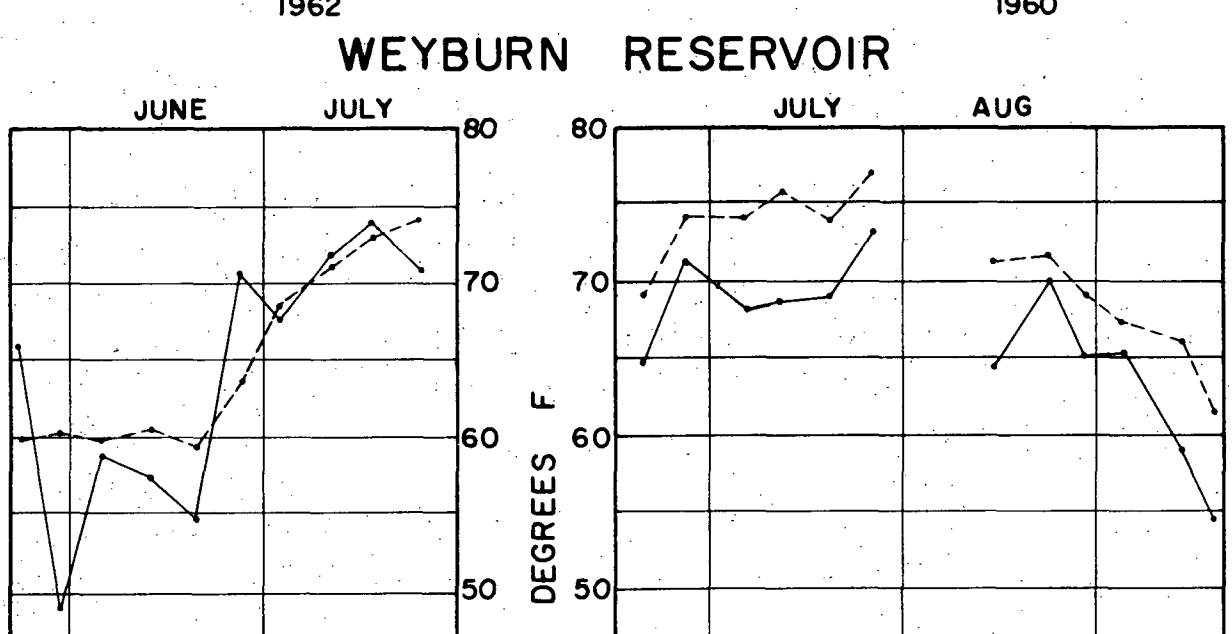
AIR TEMPERATURE.

WEEKLY – MEAN AIR AND RESERVOIR TEMPERATURES WEYBURN SASK.

FIGURE 3



WEYBURN RESERVOIR

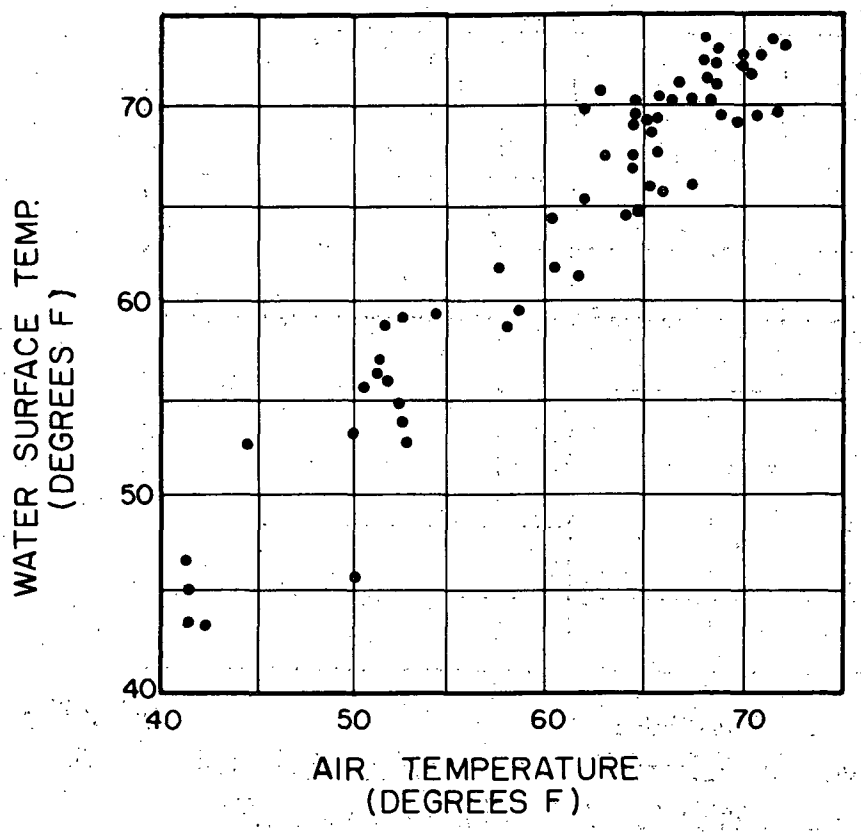


MORDEN RESERVOIR

LEGEND
---- WATER TEMPERATURE
———— AIR TEMPERATURE

WEEKLY MEAN AIR AND RESERVOIR TEMPERATURES

FIGURE 4



AIR TEMPERATURE
VS.
WATER TEMPERATURE
(WEEKLY MEANS)

WEYBURN RESERVOIR

FIGURE 5

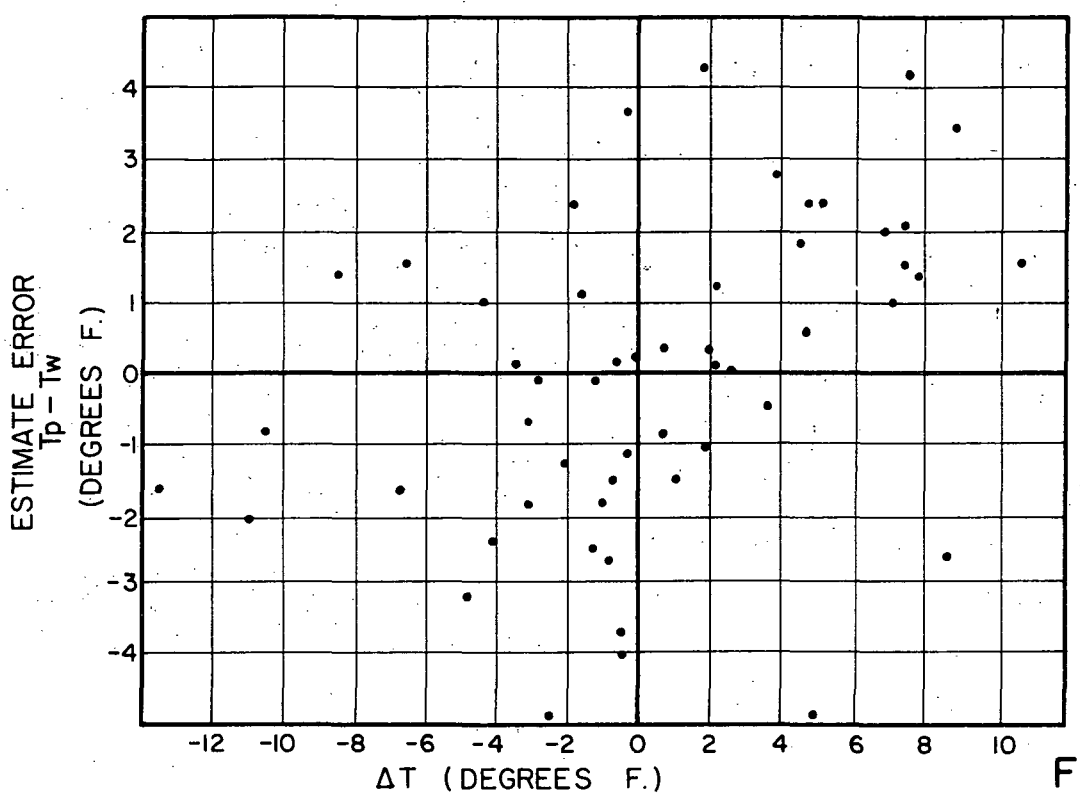


FIGURE 6

ESTIMATE ERROR Vs. INCREASE IN WEEKLY MEAN AIR TEMPERATURE

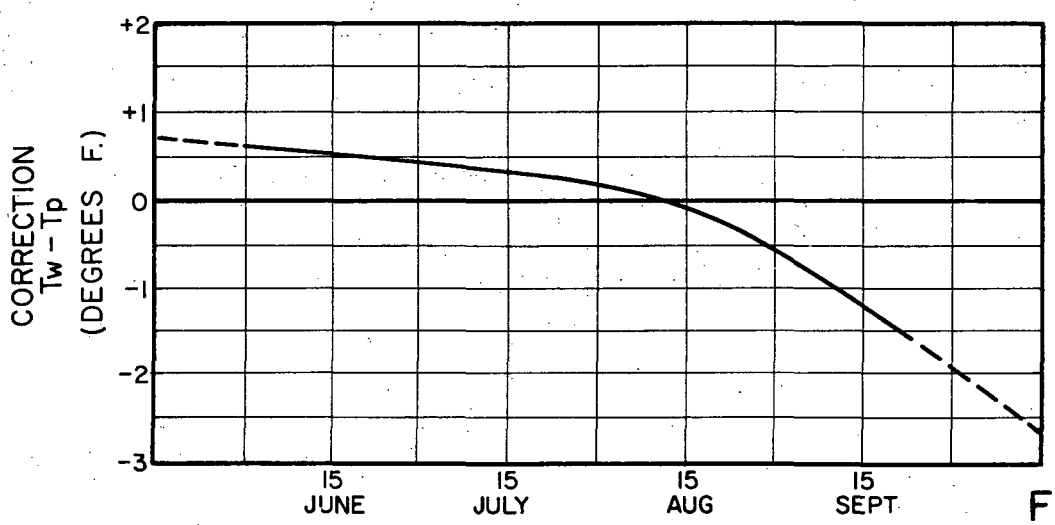


FIGURE 7

SEASONAL CORRECTION

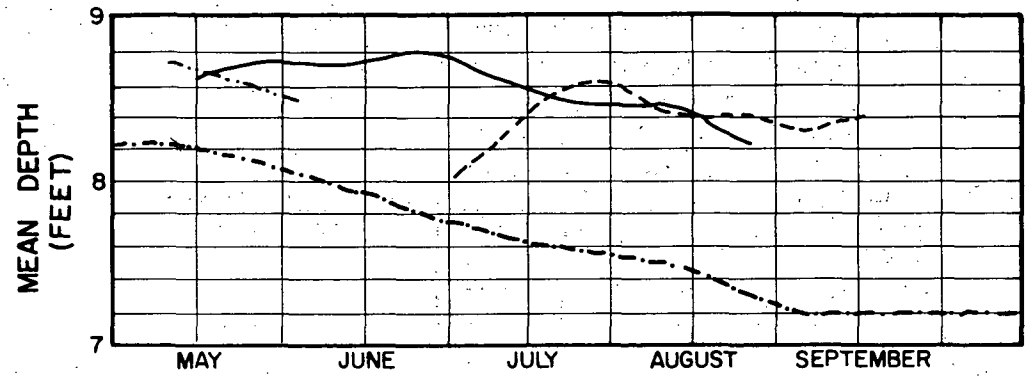
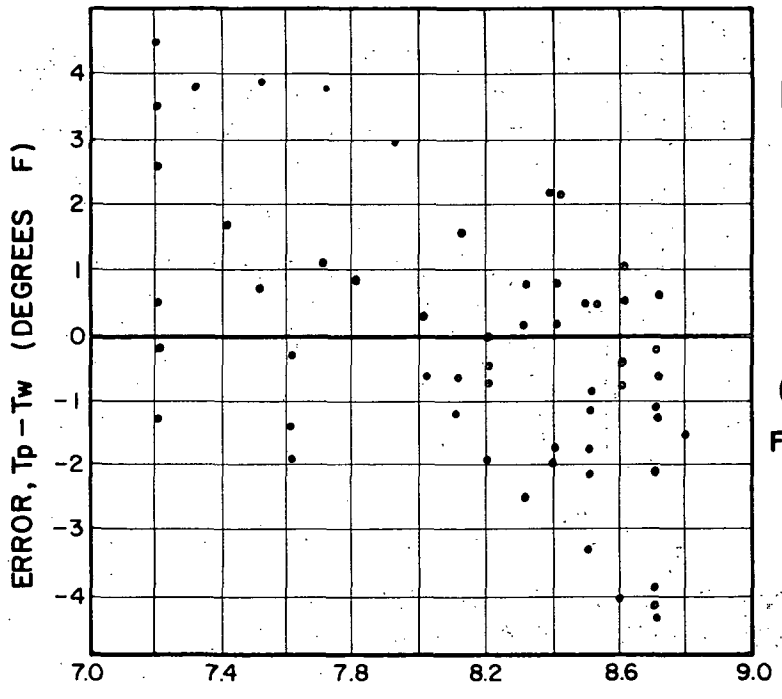


FIGURE 8

LEGEND

1961.
1962.
1963.
1964.

THE AVERAGE DEPTH OF WEYBURN RESERVOIR

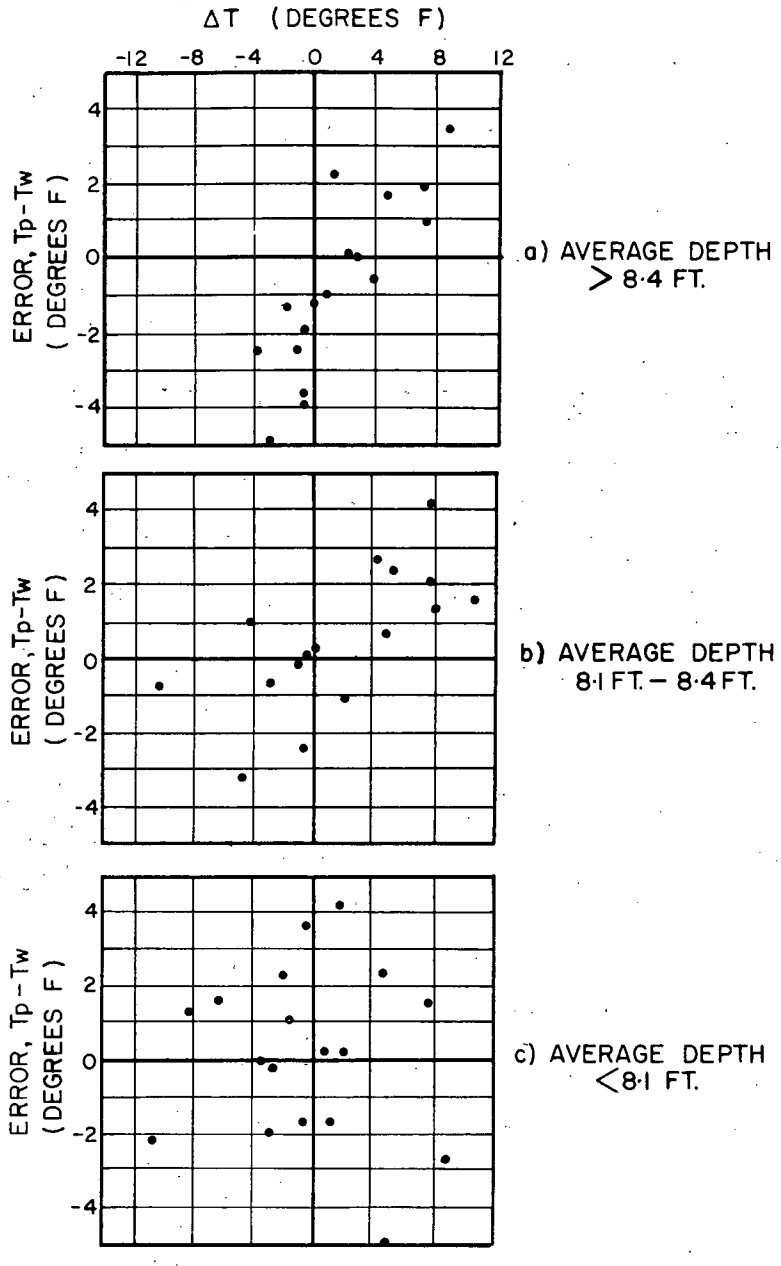


STAGE VS. ESTIMATE ERROR

WEYBURN RESERVOIR

(SEASONAL CORRECTION FOR T_p NOT APPLIED)

FIGURE 9



ESTIMATE ERROR
VS.
WEEKLY CHANGE IN AIR TEMPERATURE
FOR THREE RANGES OF STAGE

WEYBURN RESERVOIR

FIGURE 10

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Subject reference: 1. Weyburn Reservoir,
2. Morden Reservoir, 3. Water Surface
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11 pps. 9 figs. 6 tables. 1 eqn. 9 refs.

Subject reference: 1. Weyburn Reservoir,
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Temperature, 4. Solar Radiation,
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6. Regression Equation.

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CANADA
DEPARTMENT OF TRANSPORT - METEOROLOGICAL BRANCH
315 Bloor St., W., - Toronto 5, Ontario

The Estimation of the Water Surface Temperature
for Two Prairie Reservoirs
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ABSTRACT: The weekly averages of air and water surface temperature, solar radiation, wind and changes in water levels were studied for Weyburn and Morden Reservoirs to obtain relationships which were useful in the estimation of water surface mean temperature. Estimates are required for the computation of evaporation for water supply studies. The regression equation $T_w = a(T_a) + b(\ \ T_a) + c$ gave the most satisfactory results.

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