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MOBED vs HEC-6
A COMPARATIVE STUDY

by

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Study 83-328

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ABSTRACT

Models MOBED and HEC-6 were compared in this study. The comparison consisted of two steps. In step one, the major differences between the models were identified by examining the theoretical base of both models. In step two, the predictive capabilities of the models were compared by applying the models to an identical data set. The data set comes from the South Saskatchewan River reach below Gardiner Dam and relates to the degradation process that has taken place since the creation of Lake Diefenbaker. Comparison of model predictions with measurements reveals that MOBED has superior predictive capability than HEC-6 and use of HEC-6 as a predictive tool requires an extensive model calibration by the adjustment of Manning's 'n' and moveable bed width.

RESUME

Cette étude compare les modèles MOBED et HEC-6. La comparaison comporte deux étapes. La première consiste à idenfifier les différences majeures entre les modèles en examinant les fondements théoriques de chacun. Dans une deuxième étape on a comparé les capacités de prévision des modèles en les appliquant à un même ensemble de données. Ces données proviennent du tronçon de la rivière Saskatchewan-Sud situé à l'aval du barrage Gardiner et sont reliées au phénomène de dégradation observé depuis la création du lac Diefenbaker. La comparaison des prévisions des modèles aux mesures révèle que le MOBED présente des capacités de prévision supérieures au HEC-6 et que l'utilisation du HEC-6 comme instrument de prévision nécessite un étalonnage complet du modèle par ajustement du "n" de Manning et de la largeur du fond mobile.

MANAGEMENT PERSPECTIVE

This very useful comparison of two models using the same data is not done often enough. Results of this test reveal that the MOBED river model, developed at NWRI, predicts the reaction of the river bed to a change in regime better than HEC-6. It also does it with no recourse to repeated calibrtion adjustments. The report shows conclusively that the MOBED model is better and that it should be adopted by the Department as the best way to investigate the behaviour of rivers with a mobile bed subject to environmental changes in regime.

T. Milne Dick
Chief
Hydraulics Division

PERSPECTIVE DE GESTION

Cette comparaison très utile de deux modèles à l'aide des mêmes données n'est pas effectuée assez souvent. Les résultats de cet essai révèlent que le modèle MOBED, mis au point à l'INRE, prédit mieux les réactions du lit d'un cours d'eau à un changement de régime que le HEC-6. Ces prévisions sont de plus obtenues sans recours à des ajustements repétés d'étalonnage. Le rapport monte d'une manière concluante que le modèle MOBED est meilleur et qu'il devrait être adopté par le ministère comme étant la meilleure manière d'étudier le comportement des cours d'eau à lit mobile sujets à des changements écologiques de régime.

1.0 INTRODUCTION

At the request of the Sediment Survey Section of the Water Resources Branch, IWD, the Hydraulics Division of the National Water Research Institute at Burlington, Ontario, undertook a study to compare the two river flow models, MOBED and HEC-6. Both the models are useful tools for solving a number of river engineering problems. However, their range of applicability and their predictive abilities are different. A comparative study focussing on the relative merits and weaknesses of these models will be useful for practising engineers in selecting models for their particular needs. In this study, the major differences between MOBED and HEC-6 were identified and their predictive abilities were investigated by applying both models to an identical data set.

2.0 MAJOR DIFFERENCES BETWEEN MOBED AND HEC-6

The differences between MOBED and HEC-6 become apparent when the details of the models are examined. MOBED is an unsteady, mobile boundary flow model based on the numerical solution of St. Venant's equations and a sediment continuity equation. The forms of the equations solved in MOBED are given below:

$$\frac{\partial Q}{\partial t} + 2\frac{Q}{A}\left(\frac{\partial Q}{\partial X}\right) - B\frac{Q^2}{A^2}\left(\frac{\partial y}{\partial x}\right) + gA\left(\frac{\partial y}{\partial x}\right) = gA(S_x - S_f) + q_\ell\left(U_q - \frac{Q}{A}\right) + \frac{Q^2}{A^2} A^y{}_x \tag{1a}$$

$$\frac{\partial Q}{\partial x} + B\left(\frac{\partial y}{\partial t}\right) + P\left(\frac{\partial z}{\partial t}\right) = q_\ell \tag{1b}$$

$$\frac{\partial Q_s}{\partial x} + P\left(\frac{\partial z}{\partial t}\right) p + B\, C_{av}\left(\frac{\partial y}{\partial t}\right) + A\left(\frac{\partial C_{av}}{\partial t}\right) = q_s \tag{1c}$$

where

x is the longitudinal axis measured along the length of the stream (see Fig. 1)

t is the time axis

Q_s is the volumetric sediment transport rate (total load)

Q is the flow rate

y is the flow depth

z is the bed elevation

P is the wetted perimeter

p is the volume of sediment per unit volume of bed layer

B is the top width

C_{av} is the average suspended sediment concentration over a cross section

A is the flow cross-sectional area

q_s is the lateral sediment input rate

q_ℓ is the lateral inflow rate

g is the acceleration due to gravity

S_x is the slope of the river bed

S_f is the slope of the energy grade line

A_x^y is the rate of change of A with respect to x when y is held constant

The first two equations are different versions of St. Venant equations and they express the conservation of momentum and mass respectively. The third equation is the sediment continuity equation which expresses the sediment mass balance.

The slope of the energy grade line S_f appearing in equation (1a) can be evaluted once the friction factor of the flow is known. In MOBED, a general expression for S_f was derived which permits the use of different friction-factor relations without affecting the model structure. The form of the general expression for S_f used in MOBED is

$$S_f = \text{Const} \cdot \left(\frac{R}{D_{65}}\right)^m \left(\frac{V^2}{gR}\right)^n \qquad (2)$$

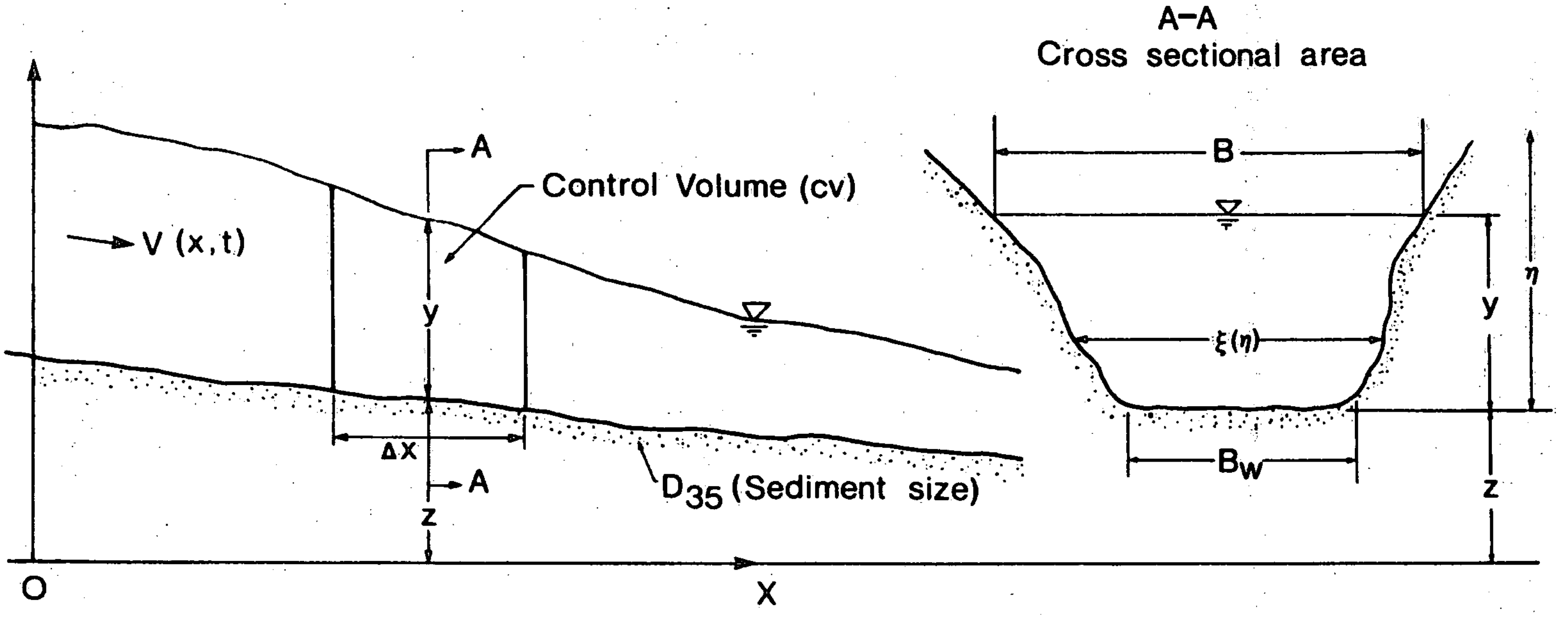

Figure 1 SCHEMATICAL REPRESENTATION OF THE LONGITUDINAL PROFILE AND A FLOW CROSS-SECTION IN A RIVER.

where Const, m and n are constants whose values depend on the friction factor relation employed;

R is the hydraulic radius;
D_{65} is the sediment size for which 65% of the material is finer
and V is the averge flow velocity.

The form of Equation (2) covers a wide range of flow conditions ranging from laminar to turbulent flows both in rigid and mobile boundaries. The values of Const, m and n for a number of friction factors corresponding to different flow regimes are summarized in Table 1.

Because of such a general expression for S_f, the model MOBED has become one of the most versatile of the existing flow models. It can be used for flows in different river types. For example, it can be used for steep rivers with gravel beds and for rivers with milder slopes and carrying fine sediments. The model can also be upgraded as new knowledge on friction factor of natural river flows becomes available.

The sediment transport rate, Q_s appearing in Equation (1c) is evaluated using the equations of Ackers and White (1973). Other equations can also be used without affecting the structure of the model as these calculations are carried out in a separate subroutine.

The model output comprises of the flow rate, the flow depth, the average flow velocity, the sediment transport rate, the bed elevations and the friction factors as functions of time and distance along the river reach. The considerations of tributary inflows, lateral input of sediments and storage basins are also possible in MOBED. For further details of the model the users manual (1981.) published by the National Water Research Institute can be consulted.

HEC-6 is a steady state model and it considers an unsteady flow as a series of steady flows of certain durations and predicts the

TABLE 1. - Values of the Parameters const, M and N for Various Friction Factor Relations

Name of Formulae	Type of Bed Form	Const	M	N
Engelund's Original Formula	Dunes	$1.86 \times 10^4 (\gamma_s/\gamma)$	-1/5	1.8
	Anti-dunes	$(0.12)^6 \cdot (\gamma/\gamma_s)^{5/3}$ γ = specific weight of fluid γ_s = submerged specific weight of sediment	-7/3	-3
Garde & Ranga Raju	Dunes & ripples	.098	-1/3	1
	Transition regime	.028	-1/3	1
	Anti-dunes	.028	-1/3	1
Kishi & Kuroki	Dune I	.0052	1.0	3
	Dune II	.013	0	1.0
	Transition I	$.018\ (\gamma_s/\gamma)^{6/7}$	-3/7	1/7
	Flat bed	.021	-1/3	1
	Anti-dunes	$.0021\ (\gamma/\gamma\ )^2$	1/5	3
Griffiths	Gravel bed	.026	-0.340	0.66
Manning's Equation	Rigid bed	$n^2 g/D^{1/3}$ n = Manning's coefficient	-1/3	1.0
Chezy's Equation	Rigid bed	g/C^2 c = Chezy's coefficient	0	1.0
Laminar flow	Rigid or Mobile Boundary	$\dfrac{3\nu}{D^{3/2}\sqrt{g}}$ ν = kinematic viscosity	-1.5	0.5

water surface elevations for these steady flows by solving the following one-dimensional energy equation of a steady flow.

$$\frac{\partial y}{\partial x} + \frac{\partial}{\partial x} (\alpha \frac{V^2}{2g}) = (S_x - S_f) \tag{3}$$

where α is a coefficient representing the horizontal distribution of velocity. After solving the water surface elevations and the flow velocities using the above equation, the bed elevations are predicted by solving the following sediment continuity equation:

$$\frac{\partial Q_s}{\partial x} + B_m \frac{\partial z}{\partial t} = q_s \tag{4}$$

where B_m is the width of the moveable bed.

For calculating the slope of the energy grade line which appears in Equation (3), the Manning's equation is adopted in HEC-6 and for computing the sediment transport rate Q_s in Equation (4) there are four equations built into HEC-6. These equations are:

1) Toffaletti's equation,
2) Madden's modification of Laursen's relationship,
3) Yang's stream power, and
4) DuBoy's equation.

The user has the option to choose any of the above four equations.

Complete details of the model can be found in the users manual (1977).

Since HEC-6 neglects the dynamic effects (compare Equations (1a and 3) it cannot be applied to cases where the flow rate changes are rapid such as flood flows and flows influenced by tides.

The sediment continuity equation used in HEC-6, i,e., Equation (4), does not account for sediment storage in the water column due to changes in suspended sediment concentration and, for this reason also, HEC-6 cannot be applied when the flow intensity variations are rapid.

The Manning's equation used to calculate the slope of the energy grade line in HEC-6, is a reasonable representation of the frictional characteristics of rigid boundary flows. For mobile boundary flows, whose bed may be covered with sand waves, Manning's equation is not very convenient because in such flows, the Manning's roughness coefficient would depend on the stage of the flow which the model endeavours to predict. This means that the model would require extensive and tedious calibrations.

A positive aspect of HEC-6 in comparison to MOBED is the treatment of the armouring of the river bed. By considering sediment material in different size fractions, HEC-6 predicts the development and stability of the armour layers for each flow rate. In MOBED, no such analysis is performed and the sediment material is represented only by two sizes, D_{50} and D_{65}. The median grain size D_{50} is utilized for the computation of sediment transport rate and D_{65} is used in the determination of the flow friction factors.

From the above discussions, it is clear that there are major differences between the two models. These differences are summarized in a Tabular form in Table 2 by comparing different aspects of MOBED and HEC-6. It is obvious from this comparison that MOBED has a wider range of applicability than HEC-6.

3.0 COMPARISON OF PREDICTIVE ABILITIES

To compare the predictive abilities of MOBED and HEC-6, both models were applied to the same data set. Since HEC-6 cannot handle unsteady flows, the selected data set should correspond to problems where the time variation of flow properties is not significant. For

TABLE 2. Major Differences Between MOBED and HEC-6

Aspects	MOBED	HEC-6	Remarks
1. <u>Governing Equations</u> a) flow	St. Venant's equations	One-Dimensional energy balance	HEC-6 considers the unsteady flow as a series of steady flows and hence the dynamic effects are neglected. Hence HEC-6 cannot be applied where the flow changes are rapid as in the case of flood flows and flows with tidal influences.
b) bed level changes	Sediment continuity equation	Sediment continuity equation	Sediment continuity equation used in HEC-6 does not account for the storage in the water column due to changes in suspended sediment concentrations and hence HEC-6 should not be applied when the flow intensity changes are rapid as in flood flows.
2. Auxilliary Equation a) friction factor	Kishi and Kuroki (1974) or other equations	Manning's equation	MOBED considers the mobile boundary roughness characteristics explicitly and also is more versatile. Different friction factor relations can be used without affecting the model structure. Manning's equation used in HEC-6 is not a convenient representation of friction factor in mobile boundary flows. In mobile boundary flows, the Manning's 'n' will depend on the flow intensity which the model endeavours to predict. HEC-6 will require extensive calibration for such flows.
b) sediment transport rate	Ackers and White (1973) or other equations	Toffaleti's equation or Madden's modification of Laursen's relationship Yang's streampower DuBoy's equation	For calculating the sediment transport rates both models have similar capabilities.
3. Treatment of Sediment Properties	Graded sediment is represented by D_{50} for calculating sediment transport rate. D_{65} is used to calculate the skin friction characteristics	Sediment material considered in different size fractions. Simulation of bed armouring is possible.	In this respect HEC-6 has a better capability than MOBED.

this reason, the problem of predicting the degradation of the South Saskatchewan River below Gardiner Dam was selected. The flow rate released from Lake Diefenbaker into the river downstream does vary with time, but the variations are not large. Also, both HEC-6 and MOBED have already been applied to this river reach. The application of HEC-6 was carried out by Northwest Hydraulic Consultants Ltd. for Saskatchewan Environment and Environment Canada in 1980. The details of the applicaton were described in a report (1980). The application of MOBED was carried out by B.G. Krishnappan (1981b) as part of the verification phase in the development of MOBED.

The data set available for the South Saskatchewan River below Gardiner Dam is very comprehensive and is suitable for both models. The data set comprises of annual surveys of flow cross-sections and samples of bed materials at a number of stations in the reach between the Gardiner Dam and Saskatoon starting from the year 1967; the year of completion of the Gardiner Dam. Fig. 2 is the location map showing the river reach and the locations of cross-sections (or ranges) where the profiles were surveyed. Each cross-section is denoted by a number which, in fact, is the distance in river miles downstream from the dam. There are a total of 27 ranges between Gardiner Dam and Saskatoon. Within this reach there are three hydrometric stations, one at range number five, the second at range number 51 and the third at Saskatoon. The water level recordings were made continuously at these stations. The flow rates released from the Gardiner Dam are measured and recorded as daily average values.

The predictions made in the earlier application of HEC-6 and MOBED were not used to compare the two models because there were some differences in the manner of application of the models. For example, HEC-6 was applied only to the first 12 miles of the river reach whereas MOBED was applied to the reach up to range 51.0. Also, in the application of HEC-6, the model was calibrated by adjusting the movable bed widths and Manning's 'n' so as to yield agreement with the measured bed levels of 1977 survey before using the model as a predictive tool.

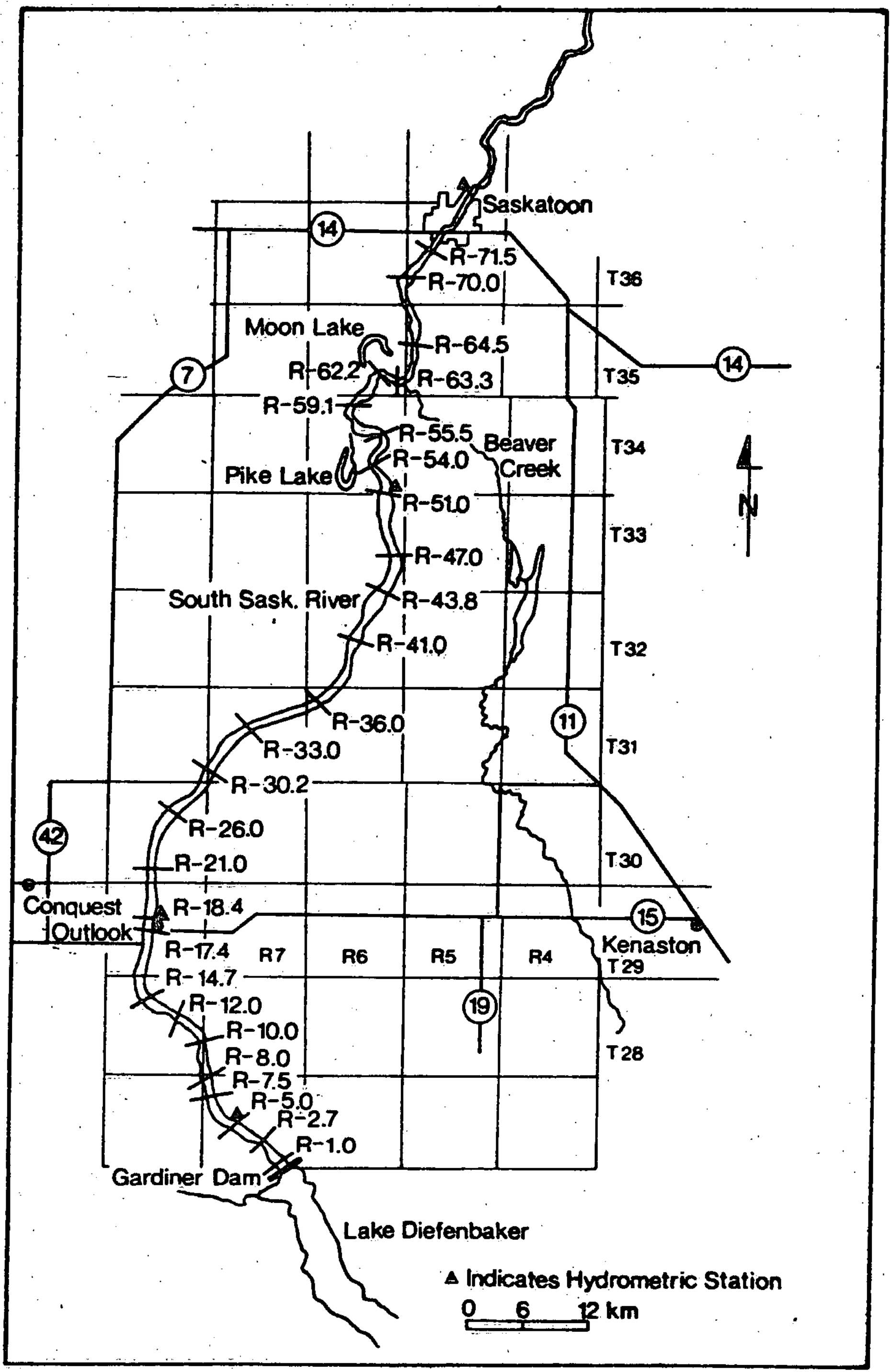

Figure 2 Location map of South Saskatchewan River below Gardiner Dam

Carte de la rivière Saskatchewan-Sud en aval du barrage Gardiner

In the case of MOBED, since it does not require calibration, the model was applied as a predictive tool using the 1967 data as initial condition. Predictions of bed levels up to 1970 were carried out and the results of 1970 were then compared with the measured bed levels for that year.

In order to make a realistic comparison of the predictive abilities of these models, it is therfore necessary to re-apply the models using the same initial condition for both models and to run the models covering the same simulation period.

In the present simulations, the data of 1967 were used as initial conditions for both the models. The river reach between range 1.0 and range 51.0 was selected and a simulation period of 10 years was chosen so that the predictions of both models corresponding to the year 1977 can be compared with data measured during that year.

For preparing input data of HEC-6, extensive use of the Northwest Hydraulic Consultants' Reports (1980)) was made. The annual flow-duration data, the bed material gradation and Manning's 'n' values reported by Northwest Hydraulic Consultants were adopted without any modification. The moveable bed width adjustment described in the Northwest Hydraulic Conulstants report (1980) was not used because, no such adjustments were made in the application of MOBED. The input data set used for running HEC-6 is shown in Appendix A.

For using MOBED, the procedure described in Krishnappan (1981b) was adopted. The predictions of MOBED up to 1970 described in Krishnappan (1981b) were retained for this study and predicitons beyond 1970 and up to 1977 were obtained by continuing the simulation. A copy of the input data file used for MOBED are shown in Appendix B.

4.0 RESULTS AND DISCUSSION

The bed levels predicted by both models for 1977 are shown in Fig. 3 together with the measured data. The initial bed levels measured in 1967 are also shown in this figure to give an indication of the extent of degradation. It can be seen from this figure that the

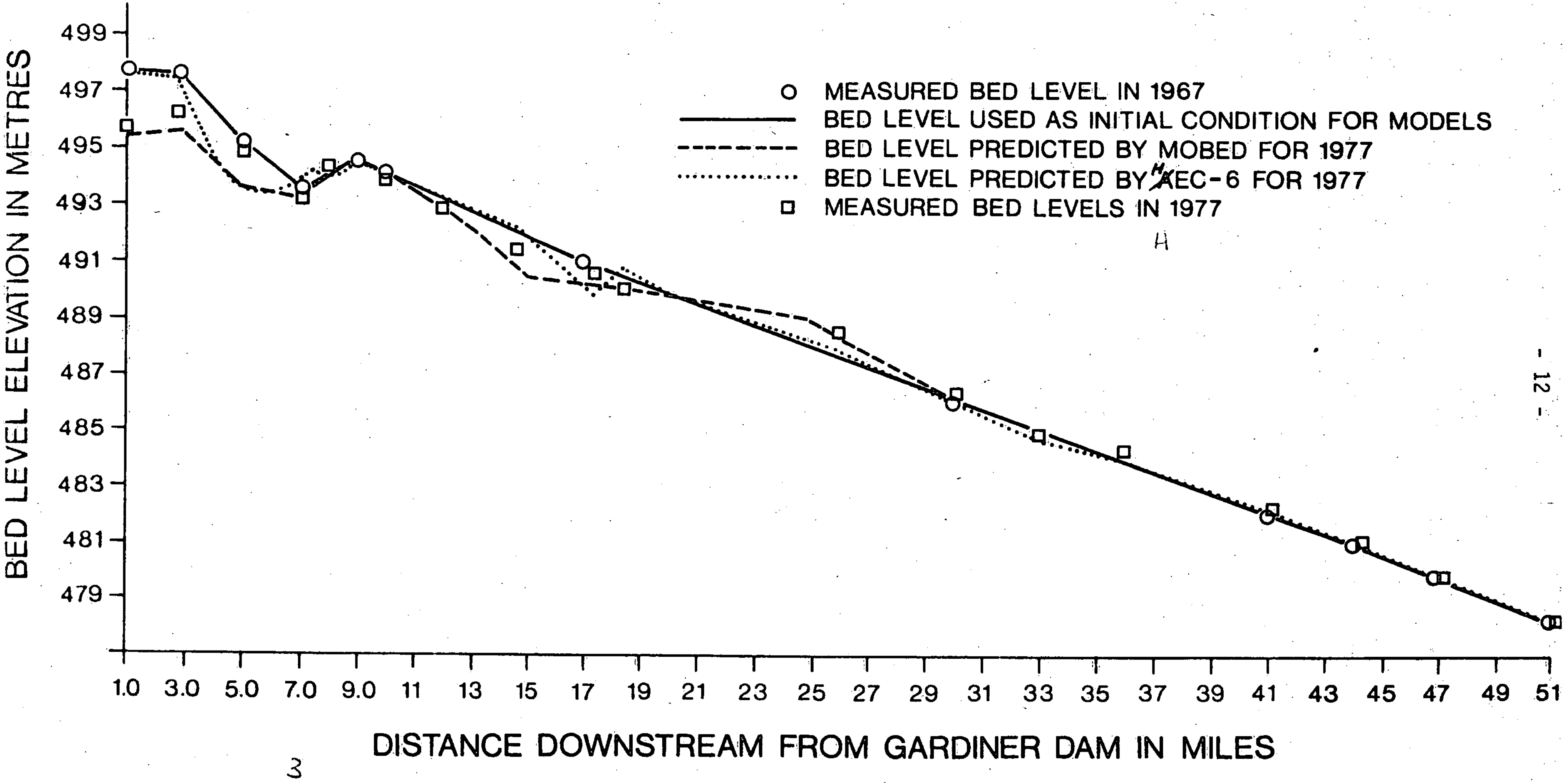

FIGURE ~~5.~~ 3 COMPARISON OF MODEL PREDICTIONS AND MEASURED BED LEVELS predictions of the models are very different especially near the upstream section of the river reach. MOBED predicts degradation right from range 1.0, but HEC-6 predictions show no significant bed level reduction up to range 3.0 and show degradation only beyond range 3.0. Measurements do indicate degradation right from range 1.0 giving support for the predictions of MOBED. MOBED predictions are somewhat higher than the measured degradation. Between ranges 3.0 and 9.0, the predictions of both models are close and agree well with measurement. Downstream of range 9.0, measured bed levels indicate degradation up to range 21.0 and aggradation between range 21.0 and range 29.0. These processes are predicted well by MOBED. The predictions of HEC-6 do indicate certain amount of degradation and aggradation in this reach but the magnitudes are not as close to measurement as those of MOBED. Downstream of range 29.0 the stream bed was not affected by the dam as of 1977. But with the passage of time, the changes would propogate further downstream. The rate of such propogation can be predicted by MOBED realistically.

In the simulations carried out by Northwest Hydraulics Consultants Ltd. with HEC-6, the model predictions were made to coincide with the measured degradation by considering the movable bed width to increase progressively from 115 metres at range 1.0 to 200 metres at range 10.0. Such an adjustment would have the effect of bringing the maximum degradation back to range 1.0 from range 5.0. If measured data are not available, then it is not possible to make such adjustments and to predict realistic degradation patterns.

From the comparison carried out in the present study, it can be concluded that the predictions of MOBED are more realistic and closer to measured values than those of HEC-6. To make realistic predictings using HEC-6, the model has to be calibrated by adjusting both the Manning's 'n' and the moveable bed widths.

5.0 SUMMARY

In this comparative study, models HEC-6 and MOBED were compared and the major differences between them were identified by examining the basis of both models. The differences between the two models are summarized in Table 1. It has been established that MOBED has a wider range of applicability than HEC-6. MOBED is an unsteady flow model whereas HEC-6 is a steady state model. Since HEC-6 neglects dynamic effects it cannot be applied to flows whose conditions change rapidly such as flood flows and flows with tidal influences. MOBED considers the mobile boundary roughness characteristics explicitly and therefore it is well suited for flows transporting sediment. HEC-6 uses Manning's 'n' and requires elaborate calibration.

The predictive abilities of these models were also compared by applying both models to same data set. The data set corresponds to the South Saskatchewan River reach below Gardiner Dam and is useful for investigating the degradation of the stream bed due to the creation of Lake Diefenbaker upstream of Gardiner Dam. Comparison of model predictions with measurements reveals that MOBED has superior predictive capability than HEC-6. It is evident from the comparison that extensive calibration is required for HEC-6 before it can be used as a predictive tool.

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APPENDIX A

Input Date for Model HEC-6

```
T1        SOUTH SASKATCHEWAN RIVER REACH HEC-6 STUDY N.W.R.I. BURLINGTON
T2                            INPUT DATA IS IN **HEC-2** FORMAT
T3             COMPARISON TO MODEL MOBED            PERIOD OF RUN - 1968
NC 0.040    0.040    0.030
X1  47.0          23 736.7004174.860      0.00      0.00      0.00    0.000     0.000
GR 736.71586.770 818.6001586.120 900.4601572.0401064.1801573.0201227.9001574.980
GR1391.61575.3101555.3401575.6401719.0601574.6501882.7801574.6502046.5001575.640
GR2210.21585.1302373.9401584.8002537.6601586.7702701.3801585.1102865.1001584.480
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GR3847.41574.6504011.1401584.1504174.8601593.970
H   47.001563.320 902.2301968.500     0.780
X1 43.80          79 163.7006548.80016896.0016896.0016896.00    0.000     0.000
GR 163.71501.180 245.5801594.830 327.4401586.770 409.3001578.590 491.1601579.400
GR 573.01579.080 654.8801579.170 736.7401579.080 818.6001579.900 900.4601581.620
GR 982.31581.5301064.1801581.2101146.0401581.6001227.9001581.5301309.7601581.920
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GR6303.21591.6806385.0801591.3606466.9401601.0206548.8001601.020
H   43.801568.000 328.0802214.570     1.400
X1 41.00          21 163.7001800.90014784.0014784.0014784.00    0.000     0.000
GR 163.71599.540 245.5801586.120 327.4401586.440 409.3001586.440 491.1601586.120
GR 573.01585.790 654.8801583.500 736.7401584.480 818.6001583.170 900.4601583.980
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GR1800.91599.540
H   41.001570.000 656.1701312.340     2.410
X1 36.00          221064.2002783.24026400.0026400.0026400.00    0.000     0.000
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GR2701.41592.0102783.2401606.750
H   36.001573.0001148.5401640.420     3.540
X1 33.00          29 982.3003274.40015840.0015840.0015840.00    0.000     0.000
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GR3028.81602.8203110.6801600.8503192.5401600.8503274.4001603.140
H   33.001580.0001017.0601558.400    -0.280
X1 30.20          151146.0003438.12014784.0014784.0014784.00    0.000     0.000
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GR2783.21597.9002946.9601597.9003110.6801596.2703274.4001594.6303438.1201611.000
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X1 26.00          31 491.2002946.90022176.0022176.0022176.00    0.000     0.000
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GR 900.51601.180 982.3201602.8201064.1801604.1301146.0401608.0601227.9001609.040
GR1309.81601.5101391.6201601.1801473.4801601.5101555.3401602.9801637.2001602.650
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GR2537.71602.9802619.5201601.8302701.3801601.1802783.2401602.4902865.1001605.110
GR2946.91611.330
H   26.001588.0001312.3402214.570     2.250
X1 21.00          33 490.3003028.82026400.0026400.0026400.00    0.000     0.000
GR 490.31616.900 491.1601608.060 573.0201609.360 654.8801611.000 736.7401611.330
GR 818.61611.660 900.4601611.990 982.3201612.6401064.1801612.9701146.0401613.620
GR1227.91615.5901309.7601614.2801391.6201614.9301473.4801614.6001555.3401615.260
GR1637.21615.5901719.0601615.2601800.9201611.3301882.7801611.9901964.6401611.330
GR2046.51611.0002128.3601608.0602210.2201606.0902292.0801605.7602373.9401605.600
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GR2865.11605.1102946.9601597.9003028.8201617.880
H   21.001588.0001804.4602985.560     0.610
X1 18.40          05 252.1002740.12013728.0013728.0013728.00    0.000     0.000
GR252.101618.810 252.1101612.160 818.6001612.1602740.1101612.1602740.1201618.810
H   18.401590.000 252.1102740.110     1.260
X1 17.40          13 163.7001800.920 5280.00 5280.00 5280.00    0.000     0.000
GR 163.71630.650 245.5801614.270 327.4401610.020 491.1601613.290 654.8801614.270
GR 818.61615.260 982.3201614.2701146.0401609.6901229.7001609.6901309.7601620.820
GR1473.51623.4401637.2001623.1201800.9201624.100
H   17.401599.140 246.300 820.210    -3.450
X1 14.70          29 940.4003274.40014256.0014256.0014256.00    0.000     0.000
GR 940.41632.610 982.3201616.0801064.1801612.0501146.0401610.1201227.9001611.000
GR1309.31614.9301391.6201617.5501473.4801614.2801555.3401615.9501637.2001620.830
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GR2455.81515.8902537.6601616.4902619.5201616.7302701.3801618.2102783.2401617.220
GR2865.01615.5902946.9601620.8303028.8201633.270
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GR3192.51630.6503356.2601635.560
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GR 000.01638.500 163.7201631.960 327.4401626.390 491.1601617.550 654.8801621.150
GR 818.61625.410 982.3201627.7001146.0401629.0101309.7601629.6601473.4801629.340
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GR3683.71635.5603765.5601636.3703847.4201638.5203929.2801644.070
H    1.001620.0002406.6303116.800    -9.310
EJ
T4 B     SEDIMENT DATA FOR MODEL SIMULATION        1968 - 1977
T5 B                 INFLOW OF SEDIMENT IS ZERO
T4 B     MODEL IS USING THE CLASSIFACATIONS 1 THRU 6 AS PER LOAD TABLE
T7 B          SUPPLIED BY NORTHWEST-HYDRAULICS
T8 B            THE FLOWS HAVE BEEN BROKEN INTO SHORT TIME SEGMENTS
I1             10.00          0
I4  SAND           0          1         6
L   WATER      100.0    90000.0
L   SEDI1      0.000      0.000
L   SEDI2      0.000      0.000
L   SEDI3      0.000      0.000
L   SEDI4      0.000      0.000
L   SEDI5      0.000      0.000
L   SEDI6      0.000      0.000
N  CS47.0                 0.000     0.000     0.000     0.000     0.050     0.250     0.500     0.120
N  CS47.0      0.050      0.030
N  CS43.8                 0.000     0.000     0.000     0.000     0.050     0.250     0.500     0.120
N  CS43.8      0.050      0.030
N  CS41.0                 0.000     0.000     0.000     0.000     0.050     0.250     0.500     0.120
N  CS41.0      0.050      0.030
N  CS36.0                 0.000     0.000     0.000     0.000     0.050     0.550     0.300     0.100
N  CS36.0      0.050      0.030
N  CS33.0                 0.000     0.000     0.000     0.000     0.050     0.250     0.500     0.120
N  CS33.0      0.050      0.030
N  CS30.2                 0.000     0.000     0.000     0.000     0.050     0.250     0.500     0.120
N  CS30.2      0.050      0.030
N  CS26.0                 0.000     0.000     0.000     0.000     0.050     0.250     0.500     0.120
N  CS26.0      0.050      0.030
N  CS21.0                 0.000     0.000     0.000     0.000     0.050     0.250     0.500     0.120
N  CS21.0      0.050      0.030
N  CS18.4                 0.000     0.000     0.000     0.000     0.050     0.250     0.500     0.120
N  CS18.4      0.050      0.030
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N CS17.4              0.000   0.000   0.000   0.000   0.050   0.550   0.300   0.100
N CS17.4     0.050    0.030
N CS14.7              0.000   0.000   0.000   0.000   0.050   0.250   0.500   0.120
N CS14.7     0.050    0.030
N CS12.0              0.000   0.000   0.000   0.000   0.050   0.250   0.500   0.120
N CS12.0     0.050    0.030
N CS10.0              0.000   0.000   0.000   0.000   0.050   0.250   0.500   0.120
N CS10.0     0.050    0.030
N CS  8.0             0.000   0.000   0.000   0.000   0.050   0.250   0.500   0.120
N CS  8.0    0.050    0.030
N CS  7.5             0.000   0.000   0.000   0.000   0.050   0.250   0.500   0.120
N CS  7.5    0.050    0.030
N CS  5.0             0.000   0.000   0.000   0.000   0.050   0.250   0.500   0.120
N CS  5.0    0.050    0.030
N CS  2.7             0.000   0.000   0.000   0.000   0.050   0.550   0.300   0.100
N CS  2.7    0.050    0.030
N CS  1.0             0.000   0.000   0.000   0.000   0.050   0.250   0.500   0.120
N CS  1.0    0.050    0.030
$HYD
$RATING
RC          11500 0.000                     1573.2201579.4201583.5201586.7501590.720
RC      1592.2601593.6701596.9201598.4201600.3801602.120
#    AB      THE FOLLOWING SEQUENCE USES 13,809.19 CFS FOR 73 DAYS
Q13809.2
T   38.00
W   73.00
#    AB      THE FOLLOWING SEQUENCE USES 16,508.83 CFS FOR 18.25 DAYS
Q16508.6
T   40.00
W   18.25
#    AB      THE FOLLOWING SEQUENCE USES 26,515.90 CFS FOR 3.65 DAYS
Q26515.9
T   42.00
W    3.65
#    AB      THE FOLLOWING SEQUENCE USES 47,526.50 FOR 3.65 DAYS
Q47526.5
T   49.00
W    3.65
#    AB      THE FOLOWING SEQUENCE USES 34,487.63 CFS FOR 3.65 DAYS
Q34487.6
T   50.00
W    3.65
#    AB      THE FOLLOWING SEQUENCE USES 21,512.37 FOR 7.30 DAYS
Q21512.4
T   55.00
W    7.30
#    AB      THE FOLLOWING SEQUENCE USES 1,901.06 FOR 146 DAYS
Q  1901.1
T    51.0
W  146.00
#    AB      THE FOLLOWING SEQUENCE USES 8,904.59 FOR 109.5 DAYS
Q  8904.6
T   42.00
W  109.50
$$END
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APPENDIX B

Input Data Files for Model MOBED

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 26     0      0       0       0       1       1        .3048 1609.3000
    .667 3216.70086400.00060467.200        9.810      0.000      0.000      0.000
    1.235      1.262      2.471      2.447      0.920      0.947      1.010      1.432
    1.424      1.446      1.411      1.477      1.591      1.585      1.596      1.591
    1.593      1.585      1.594      1.560      1.560      1.564      1.563      1.565
    1.534      1.561
  42.4800    42.4800    42.4800    42.4800    42.4800    42.4800    42.4800    42.4800
  42.4800    42.4800    42.4800    42.4800    42.4800    42.4800    42.4800    42.4800
  42.4800    42.4800    42.4800    42.4800    42.4800    42.4800    42.4800    42.4800
  42.4800    42.4800
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491.031111490.269699489.512928488.740184487.995261487.219745486.461224485.759755
485.030290484.269154483.501435482.797891482.011257481.260948480.476277479.714843
478.899725477.864880
1967    60 1
 .1000E+04 .1650E+04 .1500E-03 .1500E-03 .1000E-05
  .40
  0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
  0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
  0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
  0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
  0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
  0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
  0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
  0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
  2  1       0.000000   0.000000   0.000000   0.000000   0.000000   0.000000
    42.480     42.480     42.480     42.480     42.480     42.480     42.480     42.480
    42.480     42.480     42.480     42.480     42.480     42.480     42.480     42.480
    42.480     42.480     42.480     42.480     42.480     42.480     42.480     42.480
   212.380    256.550    284.130    285.660    284.870    285.150    282.890    284.020
   284.020    284.020    290.810    270.990    186.320    182.220    182.220    182.220
   177.550    177.550    177.550    153.620    201.470    206.260    247.770    299.110
   231.040    252.810    205.300    182.360    176.410    135.920    124.590    234.750
   249.190    249.190    152.340    130.260    145.270    258.250
   479.360    479.360    479.360    479.360    479.360    479.360    479.360    479.360
   479.360    479.360    479.360    479.360    479.360    479.360    479.360    479.360
   479.360    479.360    479.360    479.360    479.360    479.360    479.360    479.360
   479.360    479.760    480.210    480.580    480.580    480.580    480.580    480.580
   480.580    480.580    480.580    480.580    480.580    480.580    480.580    480.060
   480.060    480.060    480.060    480.060    479.910    480.060    480.360    480.520
   480.670    480.520    480.360    480.360    480.210    480.120    480.060    479.970
   480.360    480.430    480.430    480.060    479.910    480.060
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GR   130.0001640.500 150.0001638.700 170.0001637.000 190.0001634.000 210.000
GR  1633.200 230.0001633.800 245.0001635.300 265.0001635.700 285.0001636.300
GR   305.0001636.500 325.0001636.500 345.0001636.500 365.0001636.400 385.000
GR  1635.500 405.0001636.200 425.0001636.300 445.0001636.000 465.0001636.000
GR   485.0001635.800 505.0001635.700 525.0001635.500 545.0001635.100 565.000
GR  1635.200 585.0001635.400 605.0001635.300 625.0001635.000 640.0001635.200
GR   660.0001635.300 680.0001635.300 700.0001635.300 720.0001635.600 740.000
GR  1635.300 760.0001636.100 780.0001636.300 800.0001635.300 820.0001636.500
GR   840.0001636.500 860.0001636.600 880.0001636.600 900.0001636.600 920.000
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GR  3575.0001651.2003600.0001661.1003621.0001672.000
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