# A SHORT DISCUSSION ON THE INTERCOMPARISON OF TRANSMISSOMETERS USED AT CCIW

by

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**ABSTRACT**

The three transmissometer systems (two Marteks and the Multiband Transmission Temperature Profiler) currently employed as part of the in situ optical component of the Surveillance Program are breifly described and intercompared.

Methods are presented for a) converting transmission readings observed by a transmissometer system at one optical path length to the equivalent transmission readings that would be observed by the same transmissometer system at another optical path length and b) converting transmission readings observed by one transmissometer system (either Marteks or MTTP) to the equivalent transmission readings that would be observed by the other system (i.e either MTTP or Marteks).

A brief comparison between Martek and MTTP systems is also presented in terms of the relationships between in situ transmission data and inverse Secchi depth data.

Intercomparisons are performed utilizing data collected in: (1) Lake Ontario, (2) Lake Huron. The mathematical relationships presented in this report are applicable to only those waters that closely approximate, optically, waters from which the relationships were obtained.

## RÉSUMÉ

Les trois transmissomètres - deux appareils Martek et le transmissomètre-thermomètre multibandes (MTTP) - couramment utilisés par le Centre canadien des eaux intérieures (CCEI) pour des mesures optiques in situ dans le cadre de son programme de surveillance font l'objet d'une courte description et d'une comparaison.

Nous présentons des méthodes permettant: a) de convertir les données obtenues au moyen d'un transmissomètre ayant une certaine base de mesure aux données que fournirait le même transmissomètre s'il avait une autre base de mesure, et b) de couvertir les données obtenues au moyen d'un transmissomètres (un des appareils Martek ou le MTTP) aux données que fournirait l'autre appareil.

De plus, les appareils Martek et MTTP font l'objet d'une courte comparaison du point de vue de la relation entre les mesures transmissométriques in situ et l'inverse de la profondeur évaluée à l'aide d'un disque de Secchi.

Les comparaisons sont fondées sur des données obtenues dans le lac Ontario et dans le lac Huron. Les relations mathématiques présentées ici ne s'appliquent qu'à des milieux aquatiques ayant des caractères optiques presque identiques à ceux des lacs mentionnés ci-dessus.

## EXECUTIVE SUMMARY

Historically, Secchi Discs have been used as a first-order estimate of transmission of light within inland lakes. While such determinations have certainly benefitted researchers and managers alike, the quantification of such measurements suffered, quite obviously, from the highly subjective nature of the observer's involvement with the measurement process.

In an attempt to extend both the subsurface optical knowledge of lakes and the ability to quantify aquatic trends, transmissometers were introduced into the CCIW surveillance program on Great Lakes.

Through the first decade of transmissometer usage at CCIW, however, an evolution of optical devices has seen the application of three distinct transmissometers employed in lake studies (two Martek XMS systems, one utilizing a 1 m path length and the other a 0.25 m path length: an in-house designed Multiband Transmission Temperature Profiler (MTTP) utilizing a 0.25 m path length and a much narrower field of view). Consequently, original transmission data from three devices currently comprises the transmissometry data listed in the STAR data archive. These data are, understandably, not directly intercomparable, and this report is directed to those users of optical transmission data who wish to utilize these data in their original form.

The report deals with the techniques that may be readily employed to convert the data that is recorded by one transmissometer system into the equivalent data that would have been recorded by one of the other transmissometer systems, thus providing a temporal continuity in the transmission data stream.

Enough background material and theory is presented to enable an interested user to acquire an appreciation for both the nature of optical transmissometry and the intercomparison of data collected by the three CCIW devices. Examples of these intercomparisons are presented for data obtained in Lakes Ontario and Huron.

## RÉSUMÉ POUR LA DIRECTION

Le disque de Secchi est employé depuis longtemps pour évaluer la transparence de l'eau des lacs. Cet instrument a certes été utile aux chercheurs comme aux gestionnaires des ressources en eaux mais, de toute évidence, la grande part de subjectivité qui entre dans son utilisation réduit la précision des données.

Le CCEI a commencé à se servir de transmissomètres dans son programme de surveillance des Grands Lacs en vue d'améliorer les msesures optiques dans les couches inférieures et de quantifier les tendances des paramètres aquatiques.

Au cours des dix premières années où le CCEI a eu recours aux transmissomètres, l'évolution des techniques de mesure optique a entraîne l'utilisation de trois appareils distincts: deux appareils Martek XMS ayant respectivement une base de mesure de 1 et 0,25 m et un transmissomètre-thermomètre multibandes (MTTP), de conception locale, ayant une base de mesure de 0,25 m, mais un angle de champ beaucoup plus petit. La base de données STAR contient donc les données originales fournies par trois appareils. Celles-ci, on le comprendra facilement, ne peuvent être comparées directement entre elles. Ce rapport s'addresse donc à ceux qui veulent les utiliser sous leur forme originale.

Ce rapport porte sur des méthodes qui permettent de couvertir facilement les mesures effectuées au moyen d'un transmissomètre en données équivalentes pour les autres appareils et, ainsi, d'assurer la continuité temporelle des données transmissométriques.

Le lecteur aura suffisamment d'information de base et d'éléments théoriques pour se familiariser avec la transmissométrie optique et comparer les données recueillies au moyen des trois appareils du CCEI. Des exemples des comparaisons entre les données propres au lac Ontario et au lac Huron sont fournis.

## INTRODUCTION

Transmissometry was introduced at CCIW as a component of the Great Lakes Surveillance Program in 1973. The intention of such an in situ optical technique was (and is) to enable a quantification of aquatic trends which have traditionally been inferred from Secchi Disc readings, in addition to extending the optical knowledge of inland lake systems beyond that accessible to the use of Secchi Discs alone. The Secchi Depth is, clearly, a highly subjective parameter, being slavishly dependent upon the observer's vision, the sea state and incident lighting conditions, in addition to the nature and quality of the water mass itself. Since the observer and his/her surroundings are, in essence, part of the Secchi Disc measurement technique, it would seem eminently sensible to attempt such optical measurements by means of a scientifically objective optical device which would not display the same degree of extraneous dependencies.

A transmissometer, in simple terms, measures the ability of a beam of light to propagate through a given water mass. Since a transmissometer contains its own calibrated light source, the capability exists to perform transmission measurements at various depths and under any conditions of above-water radiation. Consequently, profiling of optical transmission may be obtained during periods of darkness as well as daylight.

In principle, therefore, the advent of scientifically-obtainable transmission profiles appeared to provide a much-needed

solution to the subjectiveness (and other limitations) of Secchi depth determinations. Such optimism still exists. However, as perhaps with any program involving the introduction of scientific instrumentation, there was an evolution of design philosophies which resulted in the generation of transmissometers which were not only physically different but which also produced data that were not always identical to one another. As circumstances unfolded at CCIW more than one transmissometer system was employed in the Surveillance Program (as well as in the research activities of the Environmental Optics Section), necessitating a need to intercompare transmission data. Such direct intercomparisons were not always immediately apparent. This short report is intended to illustrate how the data from the various transmissometers employed at CCIW may be rendered compatible.

The report is not intended as a treatise in the theory and/or applications of transmissometry in natural lake waters. Rather, it is directed to those interested users of the optical surveillance data who want to deal with the original transmission data as listed in the STAR data archive. The discussions presented herein should present such users with both an appreciation of what the transmission data represent and the capability of converting the transmission data recorded by or obtained from one transmissometer into equivalent transmission data that would be recorded by or obtained from another transmissometer.

## TRANSMISSOMETRY

Beam transmissometry is the measurement of the transmission of a beam of light through a given medium over a known path length. The defining equation is

$$T\,(\%) = 100\, e^{-Cx} \qquad (1)$$

or $$C(m^{-1}) = \frac{1}{x} \ln \left(\frac{100}{T(\%)}\right)$$

where $T$ = transmission in per cent

$C$ = total attenuation coefficient or beam attenuation coefficient in metres$^{-1}$

$x$ = path length in metres

Transmission of a beam of light refers to the unimpeded passage of photons through a medium. Therefore, ideally, a transmissometer will not detect any photons which have undergone interactions with the water molecules or materials present in the water. There are two types of photonic interactions that occur in the water: (1) absorption events, and (2) scattering events. In absorption events the photons are removed from the system and pose no problem to the measurement. However, in the scattering events the photons are still present in the water although they have been deviated from their initial direction of propagation. In general, the

scattering in natural waters is highly peaked in the forward direction. That is, most of the scattered photons are redirected only slightly from their initial paths within the beam (20% - 40% of the scattered photons remain within an angle of less than one degree from their initial direction). Ideally, therefore, these photons should not be recorded as having been propagated through the water as part of the collimated beam. Failure to eliminate these highly-forward scattered photons from detection would result in an erroneously high transmission value being observed. As with all optical systems the detector optics of the transmissometer has a small angular field of view (FOV) within which it accepts incident photons. Photons that are not scattered beyond the FOV of the transmissometer are recorded as having been transmitted in the beam without undergoing any interaction. To obtain the best estimate of the total attenuation coefficient, the transmissometer should have as small an angular field of view as possible.

The transmissometer is equipped with a depth sensor to obtain transmission-depth profiles, enabling the detection of particulate layering in the water column.

The transmission can be obtained for any desired spectral band by selecting an appropriate optical filter for the system. In turbid waters the spectral variation is generally quite small, becoming larger as the waters become clearer.

The value of the total attenuation coefficient obtained from transmission values and equation (1) cannot be used directly to

determine the attenuation-with-depth of incident sunlight since transmission is a consequence of beam attenuation, while the attenuation of sunlight is a consequence of diffuse attenuation. However, correlations may be computed to obtain an estimate of diffuse attenuation from beam attenuation.

## TRANSMISSOMETER SYSTEMS USED AT CCIW

Since 1973 three types of transmissometers have been used at CCIW. The first two instruments were both Martek XMS transmissometers. The only physical difference between these two instruments was the optical path length (x) employed, the path length of one being 1 metre and the path length of the other being 0.25 metre.

The Martek instruments have a FOV of 2.3°. To obtain a more accurate estimate of the true total attenuation coefficent an instrument with a narrower FOV was designed and built at CCIW. This instrument, which has a FOV of 0.9°, is referred to as the Multiband Transmission Temperature Profiler (MTTP). The MTTP system utilizes a 0.25 metre optical path length.

All transmission readings are taken using a Wratten 45 filter (centred at 485 nanometers). The MTTP, however, does possess the capability of measuring the transmission in any one of five wavelength bands.

In the STAR data archive, the transmission data are listed under STAR Code 124. The data are listed as a five-digit value consisting of four parts.

a) The first digit (as read from left to right) represents the transmissometer system which has acquired the data. The Martek XMS systems are indicated by a "0" and the MTTP system is indicated by a "1".

b) The second digit indicates the optical path length employed by the system. The 1 m path length is indicated by a "0" and the 0.25 metre path length is indicated by a "4".

c) The last two digits indicate the % transmission recorded by the transmissometer system.

According to this coding format, data from the three CCIW transmissometers would be recorded as:

| | |
|---|---|
| Martek (1 metre path length): | 0 0 0 X X |
| Martek (0.25 m path length): | 0 4 0 X X |
| MTTP: | 1 4 0 X X |

where X X represents a transmission expressed in per cent.

The presence of these three transmissometer systems at CCIW necessitates the ability to perform two types of intercomparisons:

a) the conversion of transmission readings observed by a system (either the Marteks or MTTP) at one optical path length to those transmission readings that would be observed by the same system at another optical path length.

b) The conversion of transmission readings observed by either the Marteks or MTTP systems to equivalent transmission

readings that would be observed by the other system (i.e. MTTP or Marteks).

It is tacitly assumed that the transmission data obtained by the two Martek systems may be directly compared by the optical path length conversion of (a) alone.

## OPTICAL PATH LENGTH CONVERSION

To convert a transmission reading ($T_1$) obtained from a transmissometer system at one optical path length ($X_1$) to the equivalent transmission reading ($T_2$) that would be obtained from the same transmissometer system at another optical path length ($X_2$), the following relationship may be utilized:

$$T_2(\%) = 100 \left[T_1(\%)/100\right]^{\frac{X_2}{X_1}} \qquad (2)$$

## INTERCOMPARISON OF MARTEK AND MTTP SYSTEMS IN LAKE ONTARIO

The MTTP, having a narrower field of view than the Martek, gives a better estimate of the true transmission and the true total attenuation coefficient. The transmission measured by the MTTP in natural waters is always less than that measured by the Martek since the Martek detects more of the forward scattered light.

During the first two surveys on which the MTTP was used the Martek (0.25 m optical path length) was also used to provide data for intercalibration (Lake Ontario, March, April 1980; cruise numbers 8022001 and 8022003). A total of 173 values of near surface transmission were obtained from both instruments. These transmission values were divided into two ranges ($T_{MTTP} \geq 30\%$, and $T_{MTTP} \leq 30\%$) to obtain more accurate correlations. The resulting regressions were:

a) For $T_{MTTP} \geq 30\%$

$$C_{MAR}\ (m^{-1}) = 0.882\ C_{MTTP} - 0.431 \qquad (3)$$

$$T_{MAR}\ (\%) = 1.918\ (T_{MTTP})^{0.882}$$

b) For $T_{MTTP} \leq 30\%$

$$C_{MAR}\ (m^{-1}) = 0.984 C_{MTTP} - 0.947 \qquad (4)$$

$$T_{MAR}\ (\%) = 1.364\ (T_{MTTP})^{0.984}$$

The regressions of the total attenuation coefficients are shown for the two ranges in Figures 1 and 2.

Equation sets (3) and (4) were obtained from transmission data collected at an optical path length of 0.25 metres. The values of $T_{MAR}$ obtained for 0.25 m path length from equations (3) and (4) may be converted to equivalent 1 m path length values by using equation (2). $T_{MTTP}$ is only obtained at 0.25 m optical path length. Consequently, equations (3) and (4) may be confidently used provided $T_{MAR}$ is also the appropriate 0.25 m value.

The values of the total attenuation coefficients C determined from equations (1), (3) and (4) are independent of the optical path length of the transmissometers.

It must be cautioned at this point, however, that equations (3) and (4) are not universal, but rather are strongly dependent upon the nature (in terms of the presence and types of scattering and absorption centres) of the water masses under consideration. The relationships between $T_{MAR}$ and $T_{MTTP}$ presented here are applicable only to waters that closely approximate those found in Lake Ontario at the time of surveillance cruises numbers 8022001 and 8022003.

## COMPARISON OF MARTEK AND MTTP SYSTEMS FROM SECCHI DEPTH CONSIDERATIONS FOR LAKE ONTARIO

Relationships between inverse Secchi depth and both $C_{MAR}$ and $C_{MTTP}$ were obtained for 1442 and 796 points, respectively. These relationships are shown in Figures 3 and 4 and are mathematically defined by the power law equations

$$C_{MAR} = 4.35\ (S^{-1})^{0.9} \qquad (5)$$

and

$$C_{MTTP} = 5.45\ (S^{-1})^{0.7} \qquad (6)$$

where $S^{-1}$ is the inverse Secchi depth in $m^{-1}$.

Eliminating $S^{-1}$ from equations (5) and (6) yields

$$C_{MAR} = 0.492\ (C_{MTTP})^{1.29} \qquad (7)$$

Equation (7) is plotted in Figure 5. Also included, for comparison in Figure 5, are the linear regressions between $C_{MAR}$ and $C_{MTTP}$ from Figures 1 and 2. Within the range of generally observed beam attenuation coefficient values ($1.0 \leq C_{MTTP} \leq 12.$), it is seen that equation (7) and equations (3) and (4) convert $C_{MTTP}$ to $C_{MAR}$ almost identically (< 10% difference in $C_{MAR}$ values) despite the fact that the Secchi disc suggests an obvious power law relationship while a pair of linear relationships appear to adequately describe the regression between the two sets of transmissometer readings.

## INTERCOMPARISON OF MARTEK AND MTTP SYSTEMS IN LAKE HURON

During the Lake Huron survey of May, 1984 (cruise number 8422201) transmission readings were taken using both the MTTP and the Martek (0.25 m optical path length) to provide data for intercalibration. A total of 12 pairs of readings of near surface transmission were obtained for the range of $T_{MTTP} \geq 30\%$. The resulting regression was:

For $T_{MTTP} \geq 30\%$

$$C_{MAR}(m^{-1}) = 0.846\ C_{MTTP} - 0.179 \qquad (8)$$

$$T_{MAR}(\%) = 2.125\ (T_{MTTP})^{0.846}$$

The regression of the total attenuation coefficients is shown in Figure 6.

Equation (8) was obtained from transmission data collected at an optical path length of 0.25 metres. Consequently, the transmission equation of equation (8) is applicable to transmission values taken with the appropriate 0.25 m path length.

Directly comparing equation (3) for Lake Ontario and equation (8) for Lake Huron, the salient features are the marked difference in intercept values (-0.431 and -0.197, respectively) and the close agreement (within 4%) of the slopes of the regressions (0.882 and 0.846, respectively). These features suggest that:

(1) The "background" or pristine nature of Lake Ontario and Lake Huron are significantly different.

(2) The materials that enter the water column and produce increases in the total attenuation coefficients are optically quite similar for Lake Ontario and Lake Huron.

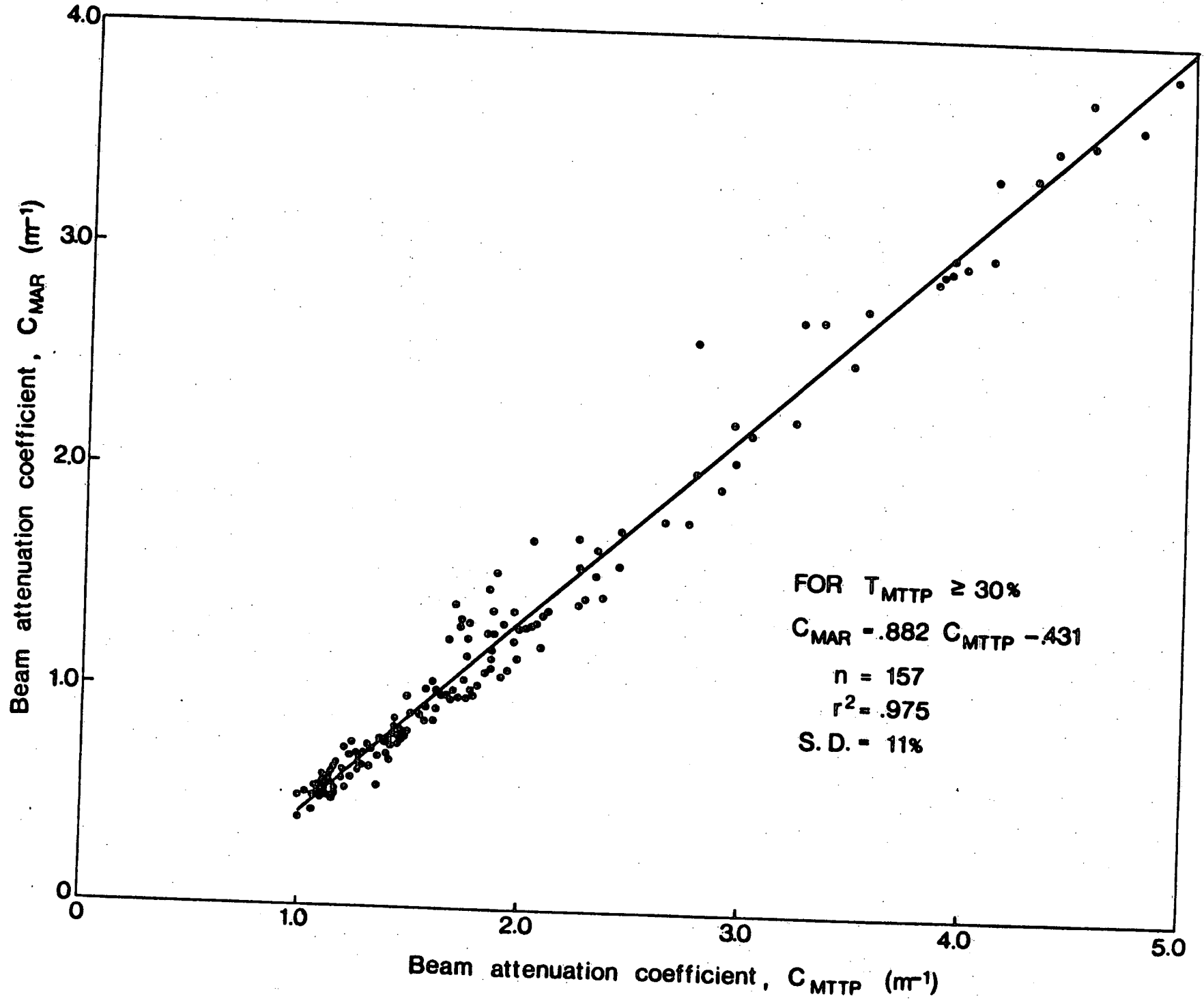
4.0
3.0
2.0
1.0
0
0
1.0
2.0
3.0
4.0
5.0
Beam attenuation coefficient, $C_{MAR}$ ($m^{-1}$)
Beam attenuation coefficient, $C_{MTTP}$ ($m^{-1}$)
FOR $T_{MTTP} \geq 30\%$
$C_{MAR} = .882\ C_{MTTP} - .431$
n = 157
$r^2 = .975$
S. D. = 11%

FIGURE 1

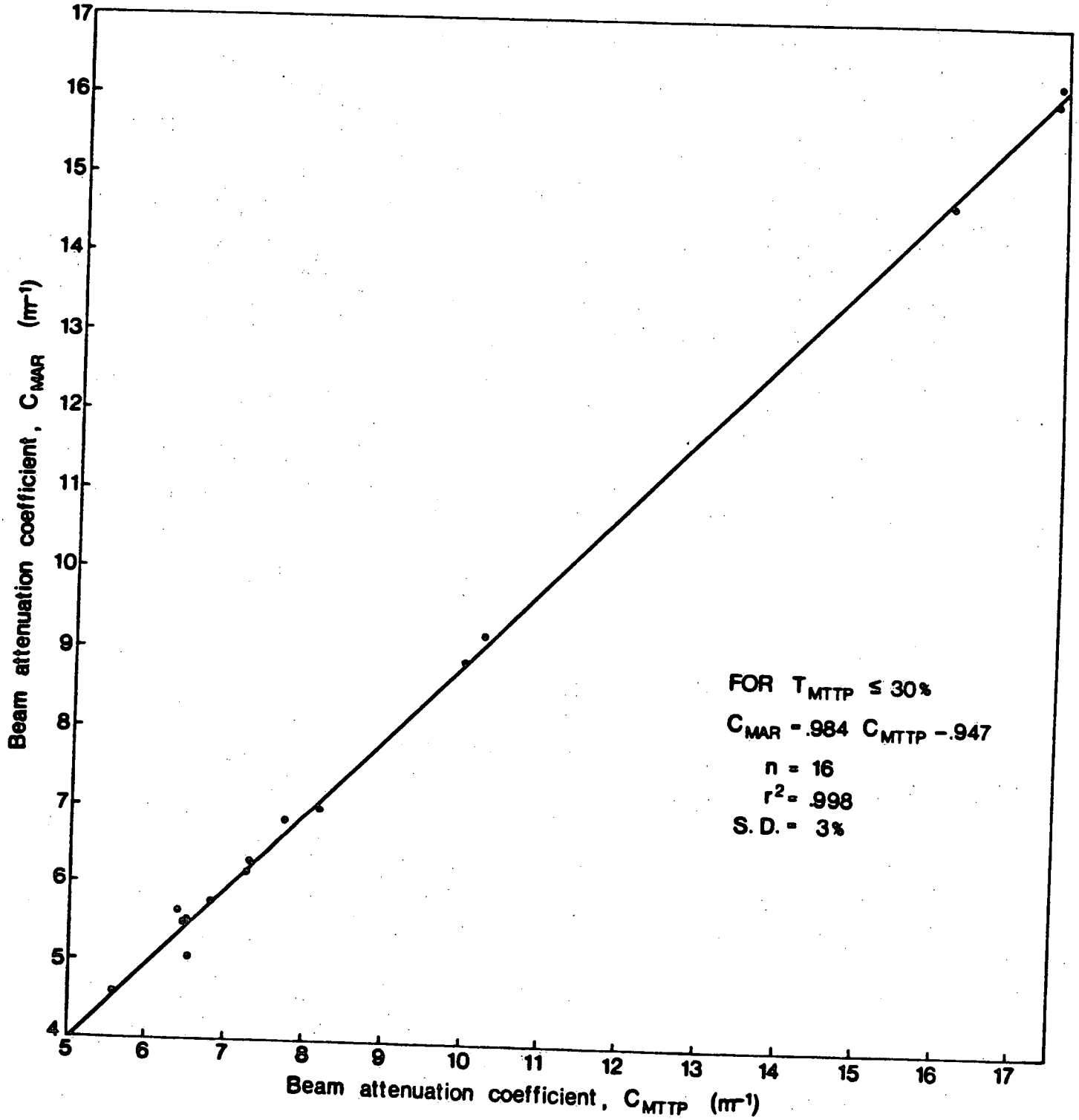
Beam attenuation coefficient, $C_{MAR}$ ($m^{-1}$)
Beam attenuation coefficient, $C_{MTTP}$ ($m^{-1}$)
FOR $T_{MTTP} \leq 30\%$
$C_{MAR} = .984\ C_{MTTP} - .947$
n = 16
$r^2 = .998$
S. D. = 3%

FIGURE 2

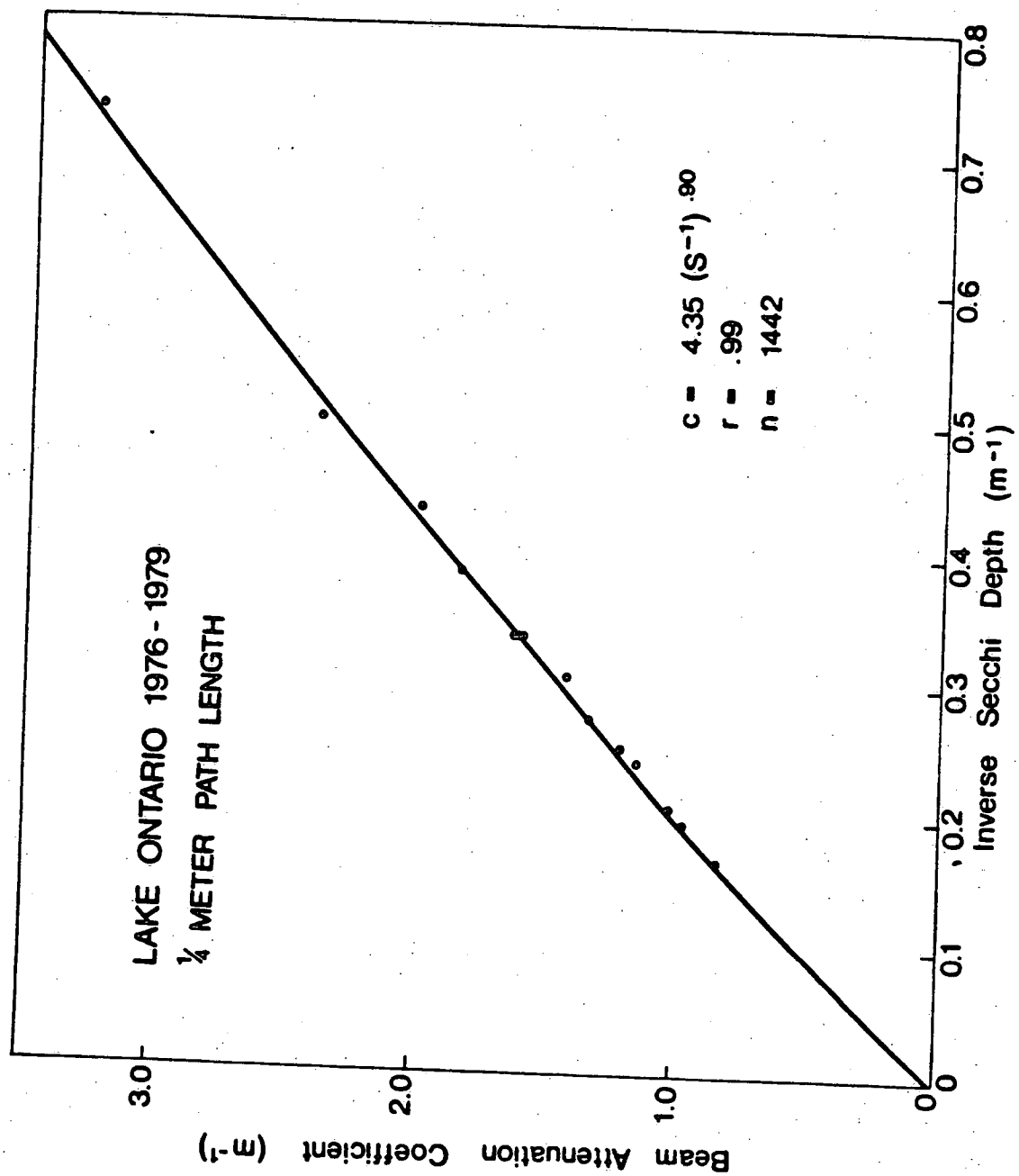
LAKE ONTARIO 1976 - 1979
¼ METER PATH LENGTH
c = 4.35 (S⁻¹) .90
r = .99
n = 1442
Beam Attenuation Coefficient (m⁻¹)
Inverse Secchi Depth (m⁻¹)
0
1.0
2.0
3.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

FIGURE 3

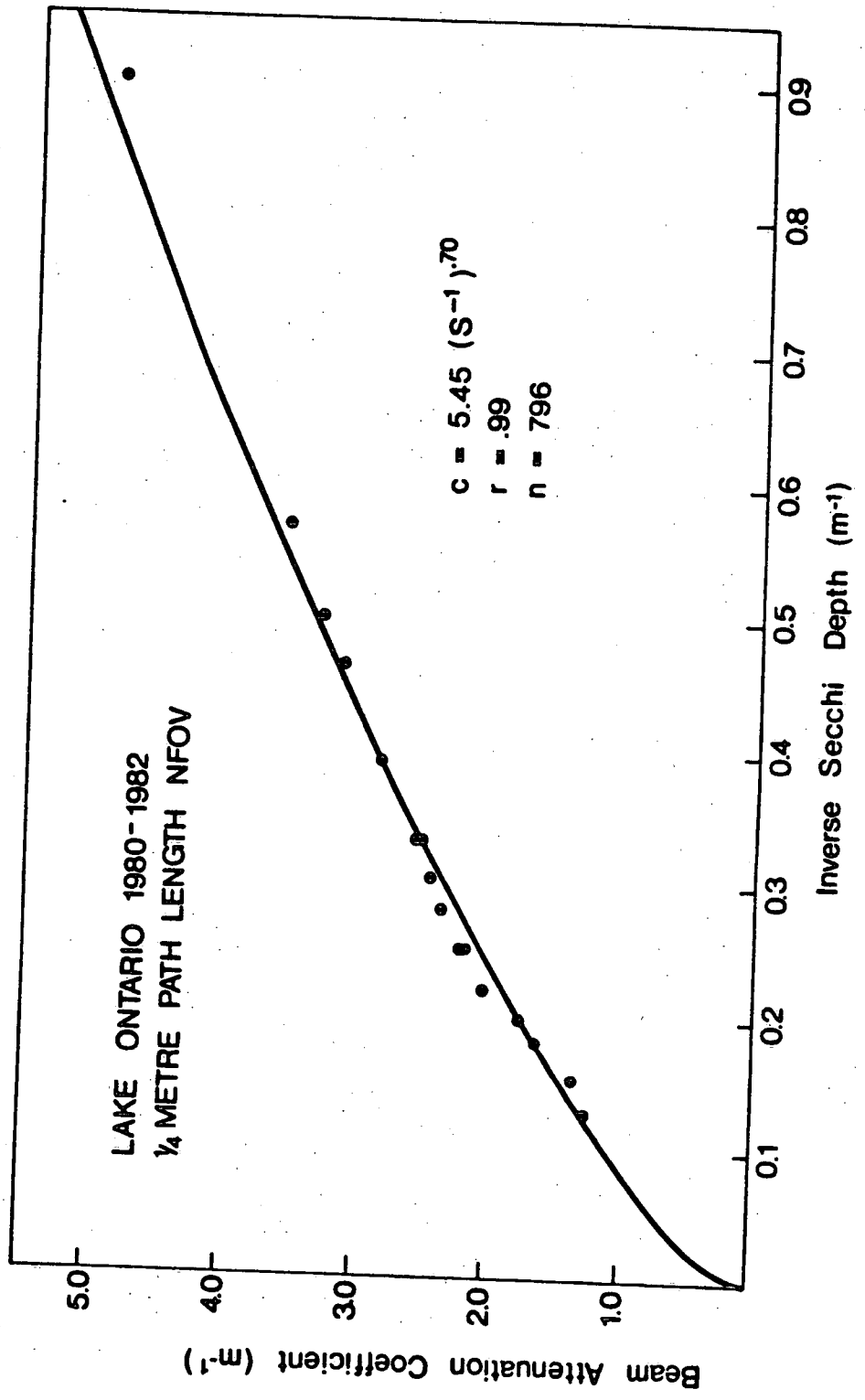
LAKE ONTARIO 1980-1982
¼ METRE PATH LENGTH NFOV
c = 5.45 (S⁻¹)·⁷⁰
r = .99
n = 796
Beam Attenuation Coefficient (m⁻¹)
Inverse Secchi Depth (m⁻¹)
5.0
4.0
3.0
2.0
1.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

FIGURE 4

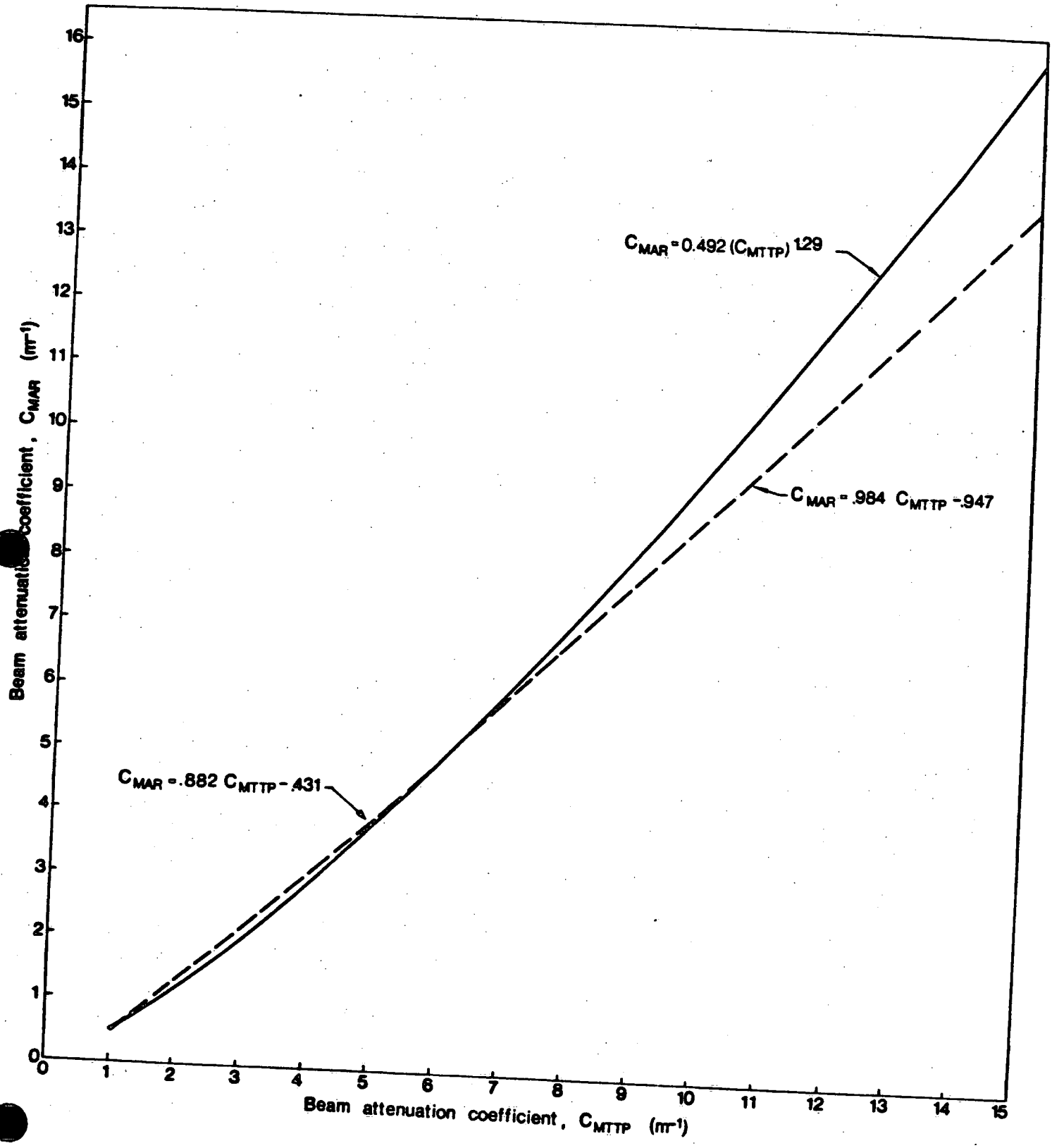
$C_{MAR} = 0.492\ (C_{MTTP})^{1.29}$
$C_{MAR} = .984\ C_{MTTP} - .947$
$C_{MAR} = .882\ C_{MTTP} - .431$
Beam attenuation coefficient, $C_{MAR}$ ($m^{-1}$)
Beam attenuation coefficient, $C_{MTTP}$ ($m^{-1}$)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

FIGURE 5

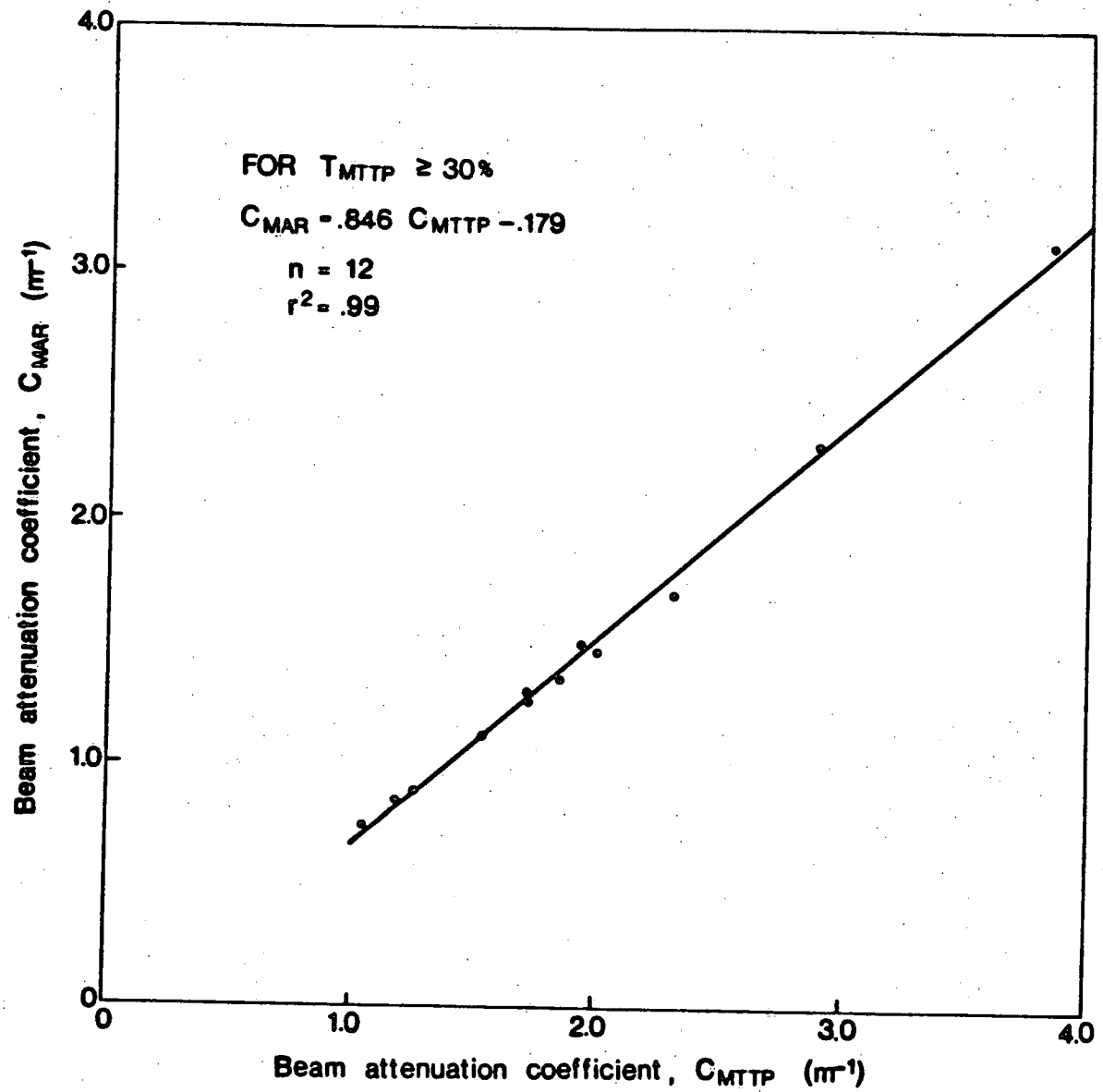
FOR $T_{MTTP} \geq 30\%$
$C_{MAR} = .846\ C_{MTTP} - .179$
n = 12
$r^2 = .99$
Beam attenuation coefficient, $C_{MAR}$ ($m^{-1}$)
Beam attenuation coefficient, $C_{MTTP}$ ($m^{-1}$)
0
1.0
2.0
3.0
4.0

FIGURE 6