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QUALITY ASSURANCE/QUALITY CONTROL DOCUMENTATION SERIES	
TITLE	**OPTICAL DATA REDUCTION AND VALIDATION (IMPROVE PROTOCOL)**
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REVISION HISTORY			
REVISION NO.	CHANGE DESCRIPTION	DATE	AUTHORIZATIONS

TABLE OF CONTENTS

LIST OF FIGURES

1.0 PURPOSE AND APPLICABILITY

This standard operating procedure (SOP) outlines the steps for data reduction and validation of optical monitoring data using IMPROVE Protocols. Optical monitoring data are collected from transmissometers or ambient nephelometers, which are used to measure atmospheric extinction (b_{ext}) and atmospheric scattering (b_{scat}), respectively. Data reduction and validation steps include:

- Processing data daily to convert raw data to Level-A validation format.
- Reviewing data visually for details on monitoring system performance.
- Processing data through Level-0 to search for questionable data and verify quality assurance codes, calibration parameters, and estimate precision.
- Processing data through Level-1 validation to compute hourly averages, calculate uncertainty values, and identify data affected by weather or optical interferences.

The following technical instructions (TIs) provide detailed information regarding specific optical data reduction and validation procedures:

- TI 4400-5000 *Transmissometer Data Reduction and Validation (IMPROVE Protocol)*
- TI 4400-5010 *Nephelometer Data Reduction and Validation (IMPROVE Protocol)*

2.0 RESPONSIBILITIES

2.1 PROGRAM MANAGER

The program manager shall:

- Review Level-1 validated data with the project manager to ensure quality and accurate data validation.
- Coordinate with the Contracting Officer's Technical Representative (COTR) for desired method of data reduction required of the IMPROVE Program.

2.2 PROJECT MANAGER

The project manager shall:

- Review and verify calibration results for each instrument.
- Review Level-1 validated data with the program manager, data analysts, and field specialists.

2.3 DATA ANALYSTS

The data analysts shall:

- Perform data validation procedures described in the appropriate technical instruction.
- Resolve data validation problems with the project manager and field specialists.
- Identify instrument or data collection and validation problems and initiate corrective actions.
- Review data with the project manager and field specialists.

2.4 FIELD SPECIALISTS

The field specialists shall:

- Review data with the project manager and data analysts.
- Provide input as to the cause of instrument problems and specific siting characteristics.

3.0 REQUIRED EQUIPMENT AND MATERIALS

All data reduction and validation occurs on IBM PC-compatible systems. The required computer system components include:

- Pentium class computer system with VGA and 80 megabyte hard disk and 64 megabytes of RAM
- Microsoft Windows98 or Windows2000 operating system and compatible printer
- Software for processing raw data:
  - ASCII text editor such as Ultraedit.32
  - File viewing utility
  - Transmissometer and nephelometer quarterly processing software

4.0 METHODS

Data reduction and validation begins with the raw data files and consists of three levels of validation: Level-A, Level-0, and Level-1. During processing of the data files, a calendar quarter data file is created for each site. Calendar quarters are defined as:

1st Quarter	(January, February, and March)
2nd Quarter	(April, May, and June)
3rd Quarter	(July, August, and September)
4th Quarter	(October, November, and December)

This sections includes two (2) major subsections:

4.1 Transmissometer Data Reduction and Validation
4.2 Nephelometer Data Reduction and Validation

4.1 TRANSMISSOMETER DATA REDUCTION AND VALIDATION

Transmissometer data reduction and validation procedures are presented in Figure 4-1, Transmissometer Data Processing Flowchart, and are described in the following subsections.

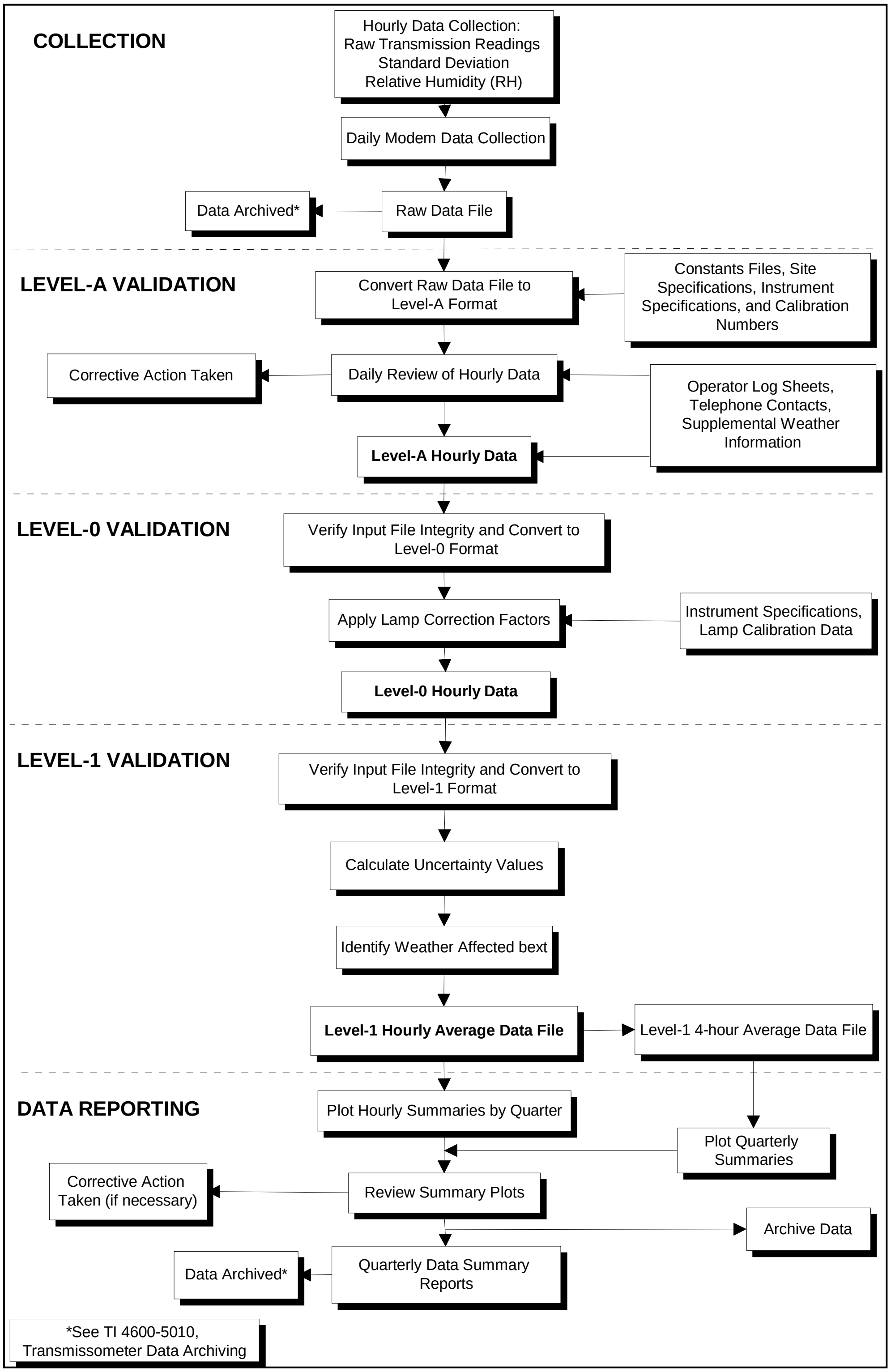

Figure 4-1. Transmissometer Data Processing Flowchart.

4.1.1 Daily Reduction and Validation Procedures

Transmissometer data collected at each monitoring site are recovered daily from satellite data collection platforms (DCPs). Along with extinction, ambient temperature and relative humidity are also monitored. The data are appended into site-specific Level-A files and reviewed to determine if the transmissometer is functioning properly. Corrective action is taken when an instrument malfunction or data problem is detected.

4.1.2 Bi-Monthly Reduction and Validation Procedures

Raw data plots are generated bi-monthly from the Level-A files. Data from operator log sheets are checked against data collected to identify inconsistencies and errors. Information from the log sheets and comments from the bi-monthly plots are entered into the Quality Assurance (QA) Database. As completed log sheets from transmissometer sites are received, the pertinent information (visibility conditions, alignment, system timing, instrument problems, etc.) is manually transferred to the bi-monthly plots. This procedure helps to identify the exact time of lamp changes, alignment corrections, and other actions done by the site operator affecting instrument operation.

4.1.3 Quarterly Reduction and Validation Procedures

4.1.3.1 Level-A Validation

Raw data files are converted to Level-A validation format on a daily basis and Level-A validation is performed on a quarterly basis. Site-specific lamp files, code files, and the processing file are all updated with the most current information available regarding lamps, instrument and support equipment operation, and calibration parameters. These files are inputted into quarterly processing software. Level-A processing performs the following functions for each site:

- Generating Level-A formatted quarterly data files, which include only the data records for the quarter to be processed.

- Recalculating b_{ext} from the raw readings, using calibration information in the lamp files.

- Removing periods in the raw file when the b_{ext} exceeds a number of consecutive times specified. In effect, this removes periods of constant b_{ext}.

- Adding validity codes specified in the code files to the raw files.

4.1.3.2 Level-0 Validation

Data and validity codes at Level-0 validation are checked for inconsistencies. The same validity codes used at Level-A apply at Level-0. Level-0 processing performs the following functions for each site:

- Generating Level-0 formatted quarterly data files, which include only the data records for the quarter to be processed.

- Correcting b_{ext} data for lamp drift. This value is based on the calculated average drift of a number of lamps.

- Generating Level-1 formatted data files (the hourly average file and the hourly average file with weather affected and validity interference codes). These files include only the data records for the quarter to be processed.

4.1.3.3 Level-1 Validation

Level-1 validation includes calculating uncertainty values for all data, and identifying b_{ext} values affected by weather or optical interferences. The data are then reduced to four-hour average values of extinction (b_{ext}), standard visual range (SVR), and haziness (dv). The time periods of the four-hour average values are:

03:00	0000 – 0359 hours
07:00	0400 – 0759 hours
11:00	0800 – 1159 hours
15:00	1200 – 1559 hours
19:00	1600 – 1959 hours
23:00	2000 – 2359 hours

The four-hour average b_{ext} and average dv, along with the average relative humidity, average temperature, and the transmissometer validity code are recorded and kept in the database.

Level-1 validated transmissometer and relative humidity data are summarized in quarterly summary plots:

- **4-Hour Average Variation in Visual Air Quality (Excluding Weather-Affected Data)**
  Timeline of 4-hour average extinction data excluding data affected by weather. The data are plotted as b_{ext} (Mm^{-1}), standard visual range (SVR), and deciview (dv).

- **Relative Humidity**
  Timeline of hourly relative humidity. Note that periods of high extinction are often associated with periods of high relative humidity.

- **Frequency of Occurrence and Cumulative Frequency Summary**
  Frequency of occurrence distribution of hourly extinction data, both including and excluding weather-affected data. The 10% to 90% values are plotted in 10% increments and are summarized in the table next to the plot. The 50% values represent the median of the valid hourly averages.

- **Visibility Metric**
  Visibility statistics for data (excluding weather-affected data), including:
  - Mean of the cleanest 20% of valid data
  - Mean of all valid data
  - Mean of the dirtiest 20% of valid data

- **Transmissometer Data Recovery**
  Data collection statistics, including:
  - Total number of hourly averages possible in the period
  - Number of valid hourly averages including weather-affected data
  - Number of valid hourly averages excluding weather-affected data
  - Percent of all valid hourly averages not affected by weather

Problems identified in the Level-1 quarterly summary plot review are resolved by editing the code, lamp, and/or constants files to identify additional data as valid or invalid and performing the Level-0 and Level-1 validation procedures again. When the Level-1 quarterly summary plots have passed the review process, the raw through Level-1 validated data and associated files are archived as described in TI 4600-5010, *Transmissometer Data Archives (IMPROVE Protocol).*

4.2 NEPHELOMETER DATA REDUCTION AND VALIDATION

Nephelometer validation begins with the raw nephelometer files and consists of three levels: Level-A, Level-0, and Level-1. Level-A validation is performed daily. Level-0 and Level-1 are performed quarterly. Data reduction and validation procedures are presented in Figure 4-2, Nephelometer Data Processing Flowchart, and is described in the following subsections.

4.2.1 Daily Reduction and Validation Procedures

Level-A validation of raw nephelometer and meteorological data occurs daily, immediately after collection. Validation tasks performed are:

- Parameters are extracted from the raw file and are appended to site-specific quarterly data files (raw scattered light, direct light, chamber temperature, status code, normalized scattered light, ambient temperature, relative humidity, and power failure information).

- Clean air zero and span calibrations recorded by the datalogger are extracted from the raw data file and appended to instrument-specific QA calibration files.

- Validity codes are assigned to the nephelometer data. Meteorological data are not assigned validity codes.

After Level-A validation, the data and operator log sheets are visually reviewed to identify operational problems and initiate corrective procedures. Level-A validated data are plotted weekly. Comments regarding the operation of the nephelometer are noted on the plots. If a new problem is identified beyond those discovered in the daily data review, corrective actions are initiated.

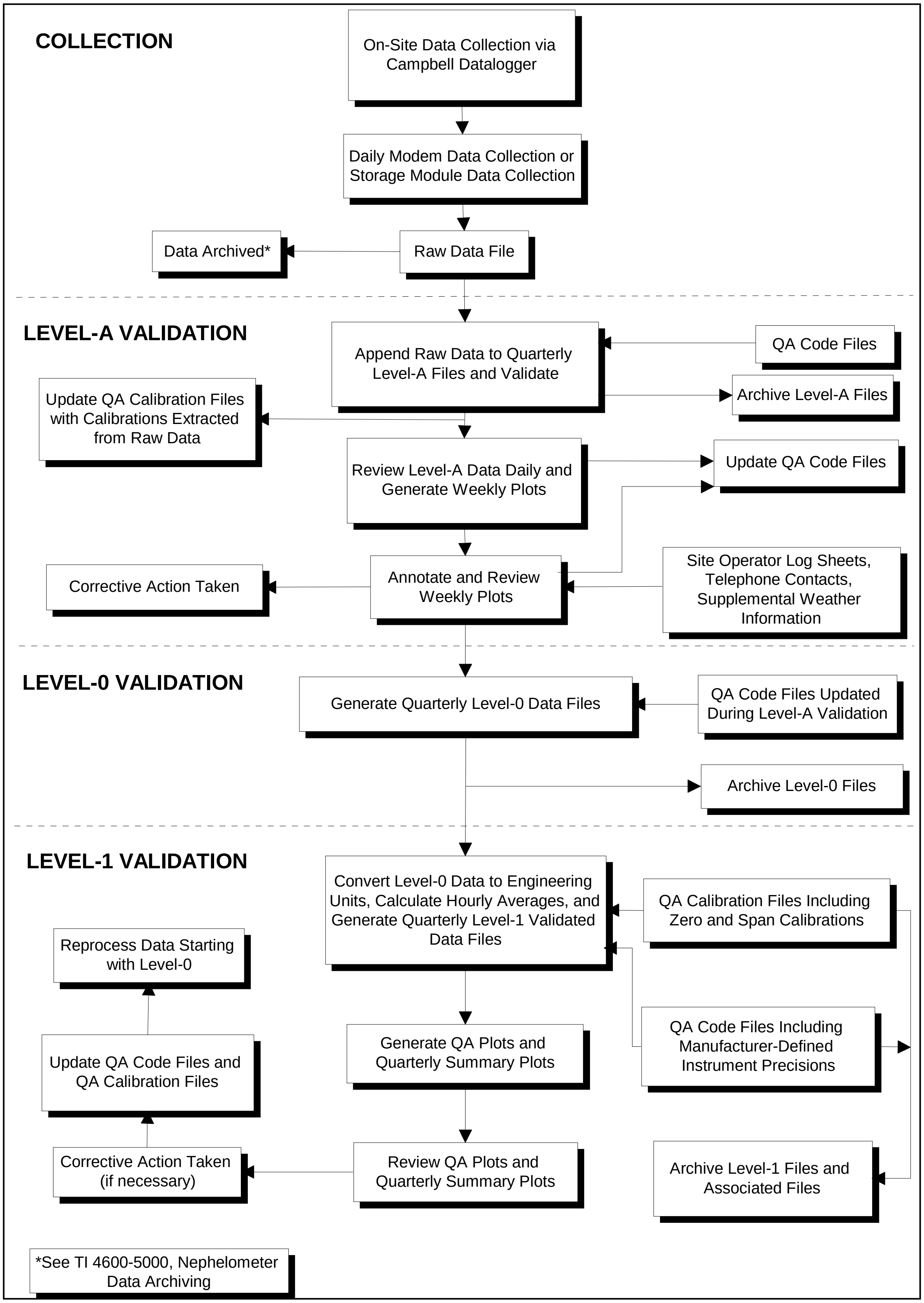

Figure 4-2. Nephelometer Data Processing Flowchart.

4.2.2 Quarterly Reduction and Validation Procedures

Quarterly reduction and validation includes updating code files, calibration files, and processing through Level-0 and Level-1 validation.

4.2.2.1 Updating Files

QA code files and QA calibration files are updated quarterly and are inputted into quarterly processing software.

The QA code files are site-specific files containing the time-tagged operational history of each site. Each file includes QA codes that identify periods as invalid, precision estimates, QA calibration file names, and a Rayleigh coefficient.

The QA calibration files are nephelometer-specific files containing all zero and span calibrations performed on a nephelometer during a specific time period, including the initial zero and span performed during installation. The calibration information in the QA calibration files is used during data reduction to calculate the scattering coefficient based on the raw data and to estimate the precision of that data. The files also include parameters to help identify invalid calibrations.

QA calibration plots are generated showing nephelometer zero and span calibrations recorded in the instrument-specific QA calibration files, and an estimate of the precision of the nephelometer data based on those calibrations. Final QA calibration plots are generated after validating the zero and span calibrations based on the preliminary plots. Any invalid calibrations shown on the final plots as valid must be edited manually. Uncertainty estimates generated during QA calibration plot review are entered manually in the QA code files. The uncertainty estimates appear in the Level-1 data file for reference.

4.2.2.2 Level-0 Validation

Level-0 validation of nephelometer and meteorological data is performed quarterly. The Level-A data and plots are reviewed to identify periods of invalid nephelometer data caused by a burned out lamp, power failures, water contamination, or other problems. Level-A meteorological data are also reviewed to identify invalid periods caused by sensor failures. Corrective actions are initiated if required.

The nephelometer data validation constants file (Nprocess.con) is updated and verified for correct information and contains the following:

Level-0 Validation Constants	Level-1 Validation Constants
Raw nephelometer underrange and overrange	Nephelometer raw standard deviation / mean filter
Raw nephelometer rate-of-change	Nephelometer b_{scat} rate-of-change filter
Ambient temperature underrange and overrange	Nephelometer b_{scat} RH filter
Relative humidity underrange and overrange	Nephelometer b_{scat} maximum filter

The constants file is then used to generate Level-0 validated nephelometer data.

4.2.2.3 Level-1 Validation

Level-1 validation of nephelometer and meteorological data is performed quarterly following Level-0 validation. Level-1 validation performs the following tasks:

- Computing hourly averages from Level-0 data
- Validating QA calibration file entries
- Converting hourly average data to engineering units
- Performing overrange/underrange checks
- Identifying nephelometer b_{scat} data affected by meteorological interference
- Estimating precision

Level-1 validated nephelometer and relative humidity data are summarized in quarterly summary plots:

- **4-Hour Average Variation in Visual Air Quality (Filtered Data)**
  Timeline of 4-hour average scattering data filtered to remove data affected by meteorological interference. The data are plotted as b_{scat} (km^{-1}).

- **Relative Humidity**
  Timeline of hourly relative humidity. Note that periods of high scattering are often associated with periods of high relative humidity.

- **Frequency of Occurrence and Cumulative Frequency Summary**
  Frequency of occurrence distribution of hourly scattering data, both unfiltered and filtered for meteorological interference. The 10% to 90% values are plotted in 10% increments and are summarized in the table next to the plot. The 50% values represents the median of the valid hourly averages.

- **Visibility Metric**
  Visibility statistics for data filtered for meteorological interference, including:
  - Mean of the cleanest 20% of valid data
  - Mean of all valid data
  - Mean of the dirtiest 20% of valid data

- **Nephelometer Data Recovery**
  Data collection statistics, including
  - Total number of hourly averages possible in the period
  - Number of valid hourly averages including filtered and unfiltered data
  - Number of valid hourly averages including filtered data only
  - Filtered data as percent of unfiltered and filtered data

Problems identified in the Level-1 quarterly summary plot review are resolved by editing the QA code and/or calibration files to identify additional data as valid or invalid and performing the Level-0 and Level-1 validation procedures again. When the Level-1 quarterly summary plots have passed the review process, the raw through Level-1 validated data and associated QA files are archived as described in TI 4600-5000, *Nephelometer Data Archives (IMPROVE Protocol).*

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QUALITY ASSURANCE/QUALITY CONTROL DOCUMENTATION SERIES	
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OTHER		

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1.0	Add discussion regarding Olympus lamps	March 1995	
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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (continued)

Figure **Page**

1.0 PURPOSE AND APPLICABILITY

This technical instruction (TI) describes the steps of transmissometer data reduction and validation, to assure quality data and ensure that data are placed in a format consistent with IMPROVE Protocol. This TI is referenced in SOP 4400, *Optical Monitoring Data Reduction and Validation (IMPROVE Protocol)*.

A transmissometer directly measures the irradiance of a light source after the light has traveled over a finite atmospheric path. The transmittance of the path is calculated by dividing the measured irradiance at the end of the path with the calibrated initial intensity of the light source. The average extinction of the path is calculated using Bouger's law from the transmittance and length of the path. It is attributed to the average concentration of all atmospheric gases and ambient aerosols along the path.

This TI presents the detailed steps used to ensure high quality data reduction and validation from transmissometer stations operated according to IMPROVE Protocol:

- Processing data daily to convert the raw data to Level-A validation format.
- Reviewing data visually and examining any error files for details on monitoring system performance.
- Processing data through Level-0 validation to search for questionable or physically unrealizable data.
- Processing data through Level-1 validation to calculate uncertainty values and identify values affected by weather or optical interferences.

Because most stations are remote, daily data review is critical to the identification and resolution of problems.

2.0 RESPONSIBILITIES

2.1 PROGRAM MANAGER

The program manager shall:

- Review Level-1 validated data with the project manager to ensure quality and accurate data validation.
- Coordinate with the Contracting Officer's Technical Representative (COTR) for desired method of data reduction required of the IMPROVE Program.

2.2 PROJECT MANAGER

The project manager shall:

- Review and verify calibration results for each instrument.
- Review Level-1 validated data with the program manager, data analysts, and field specialists.

2.3 DATA ANALYSTS

The data analysts shall:

- Perform data validation procedures described in this technical instruction.
- Resolve data validation problems with the project manager and field specialists.
- Identify instrument or data collection and validation problems and initiate corrective actions.
- Review data with the project manager and field specialists.

2.4 FIELD SPECIALISTS

The field specialists shall:

- Review data with the project manager and data analysts.
- Provide input as to the cause of instrument problems and specific siting characteristics.

3.0 REQUIRED EQUIPMENT AND MATERIALS

All data reduction and validation occurs on IBM PC-compatible systems. The required computer system components include:

- Pentium class computer system with VGA and 80 megabyte hard disk and 64 megabytes of RAM
- Microsoft Windows98 or Windows2000 operating system and compatible printer
- Software for processing raw transmissometer data:
  - ASCII text editor such as Ultraedit.32
  - File viewing utility
  - ARS plotting (LPV_plot.exe) and quarterly processing software (LPV_seas.exe)
- Completed operator log sheets

4.0 METHODS

This section describes the processing procedures applied to transmissometer data to obtain extinction, SVR, and deciview data in IMPROVE Protocol format, and includes three (3) subsections:

4.1 Daily Reduction and Validation Procedures
4.2 Bi-Monthly Reduction and Validation Procedures
4.3 Quarterly Reduction and Validation Procedures

4.1 DAILY REDUCTION AND VALIDATION PROCEDURES

Data collected at each monitoring site are recovered daily from satellite data collection platforms (DCPs). Along with extinction, ambient temperature and relative humidity are also monitored. The data represent one 10-minute average value for each hour. The measurement interval begins 3 minutes after the hour and ends at 13 minutes after the hour.

Once the data are appended into site-specific Level-A files (see TI 4300-4023, *Transmissometer Daily Compilation and Review of DCP-Collected Data (IMPROVE Protocol)*), the data analysts review each Level-A file (*xxxxx*_T.*yyq* where *xxxxx* is the five-character site abbreviation, *yy* is the year, and *q* is the quarter [1, 2, 3, or 4]) using an ASCII text editor. The Level-A files are located in the O:\Trans\Daily directory of the ARS computer network. Each *xxxxx*_T file is reviewed to determine if the transmissometer is functioning properly. Corrective action is taken when an instrument malfunction or data problem is detected. Data analysts contact the site operator by telephone and initiate troubleshooting procedures (see TI 4110-3300, *Troubleshooting and Emergency Maintenance Procedures for Optec LPV-2 Transmissometer Systems (IMPROVE Protocol)*) and TI 4110-3305, *Troubleshooting and Emergency Maintenance Procedures for Optec LPV-3 Transmissometer Systems (IMPROVE Protocol)*.

4.2 BI-MONTHLY REDUCTION AND VALIDATION PROCEDURES

Raw data plots are generated bi-monthly from the *xxxxx*_T files. Data from operator log sheets are checked against data collected via data collection platforms (DCPs) to identify inconsistencies and errors. Information from the log sheets and comments from the bi-monthly plots are entered into the Quality Assurance (QA) Database. All hard copy log sheets are chronologically filed by site.

4.2.1 Bi-Monthly Data Plots

Level-A transmissometer data are plotted bi-monthly using ARS plotting software (LPV_plot.exe). The plots are displayed on the large corkboard outside the Data Collection Center (DCC) and are reviewed by the project manager, data analysts, and field specialists on a monthly basis. Inconsistent or suspicious data are identified and troubleshooting procedures are initiated (see TI 4110-3300 and TI 4110-3305).

4.2.2 Comments on Plots

As completed log sheets from transmissometer sites are received, the pertinent information (visibility conditions, alignment, system timing, instrument problems, etc.) is manually transferred to the bi-monthly plots. Figure 4-1 is an example bi-monthly data plot with comments. This procedure helps to identify the exact time of lamp changes, alignment corrections, and other actions done by the site operator affecting instrument operation. The data analysts can then use this information to correctly update the lamp and code files for Level-A validation (see Section 4.3.1).

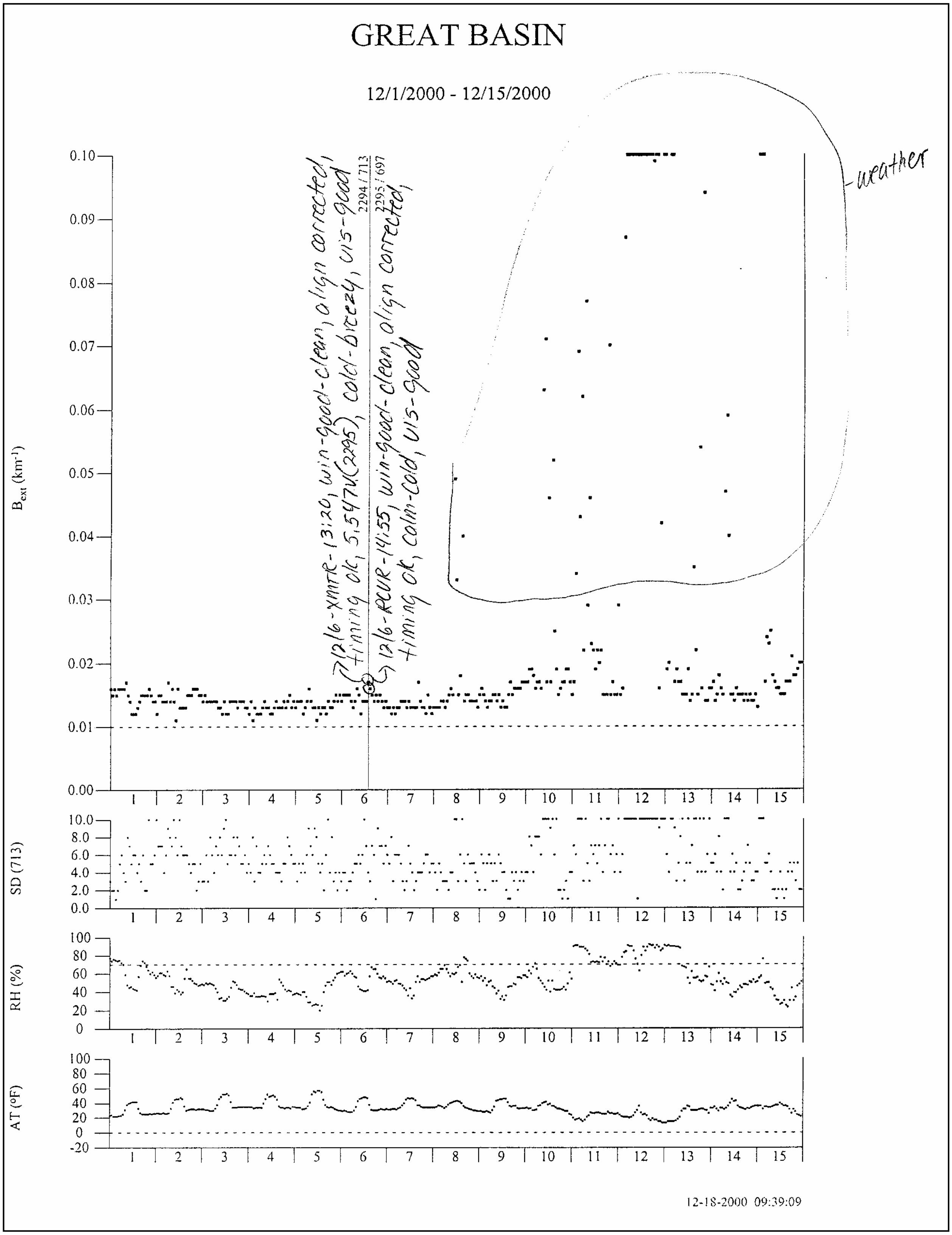


Figure 4-1. Example Bi-Monthly Data Plot With Comments.

4.3 QUARTERLY REDUCTION AND VALIDATION PROCEDURES

Data analysts create a calendar quarter data file for each site. Calendar quarters are defined as:

1st Quarter	(January, February, and March)
2nd Quarter	(April, May, and June)
3rd Quarter	(July, August, and September)
4th Quarter	(October, November, and December)

Processing begins with the raw transmissometer files (*xxxxx*_T.*yyq*) and consists of three levels of data validation: Level-A, Level-0, and Level-1. Processing at each level is presented in Figure 4-2, Transmissometer Data Processing Flowchart, and described in the following subsections.

4.3.1 Level-A Validation

Raw data files are converted to Level-A validation format on a daily basis. Level-A validation, performed on a quarterly basis, includes updating constants files and processing the data files. Procedures for Level-A validation are:

UPDATE CONSTANTS FILES

Lamp and Processing Files

Refer to TI 4300-4023, *Transmissometer Daily Compilation and Review of DCP Collected Data (IMPROVE Protocol)*, for a description of the procedures for updating the site-specific lamp files (*xxxxx*_L) and the processing file (Tprocess.con).

Code Files

The site-specific code files include the following information:

- Beginning and ending dates and times that identify invalid data
- Codes indicating reason for invalid data
- Comments describing specific reason for invalid data

The information in the code files is required to identify known periods of invalid data. The code files must be edited with the most current information available regarding instrument and support equipment operation. Each site has its own code file with the file name *xxxxx*_C, where *xxxxx* is the site abbreviation.

To edit individual code files:

- Locate the code files on the computer network, in the O:\Trans\Site.con directory.
- Edit an individual code file using an ASCII editor. The file format for code files is detailed in Figure 4-3.
- Edit the fields in the code file to reflect current information regarding the instrument and support equipment operation. Commas must be included between fields.
- Save the file.

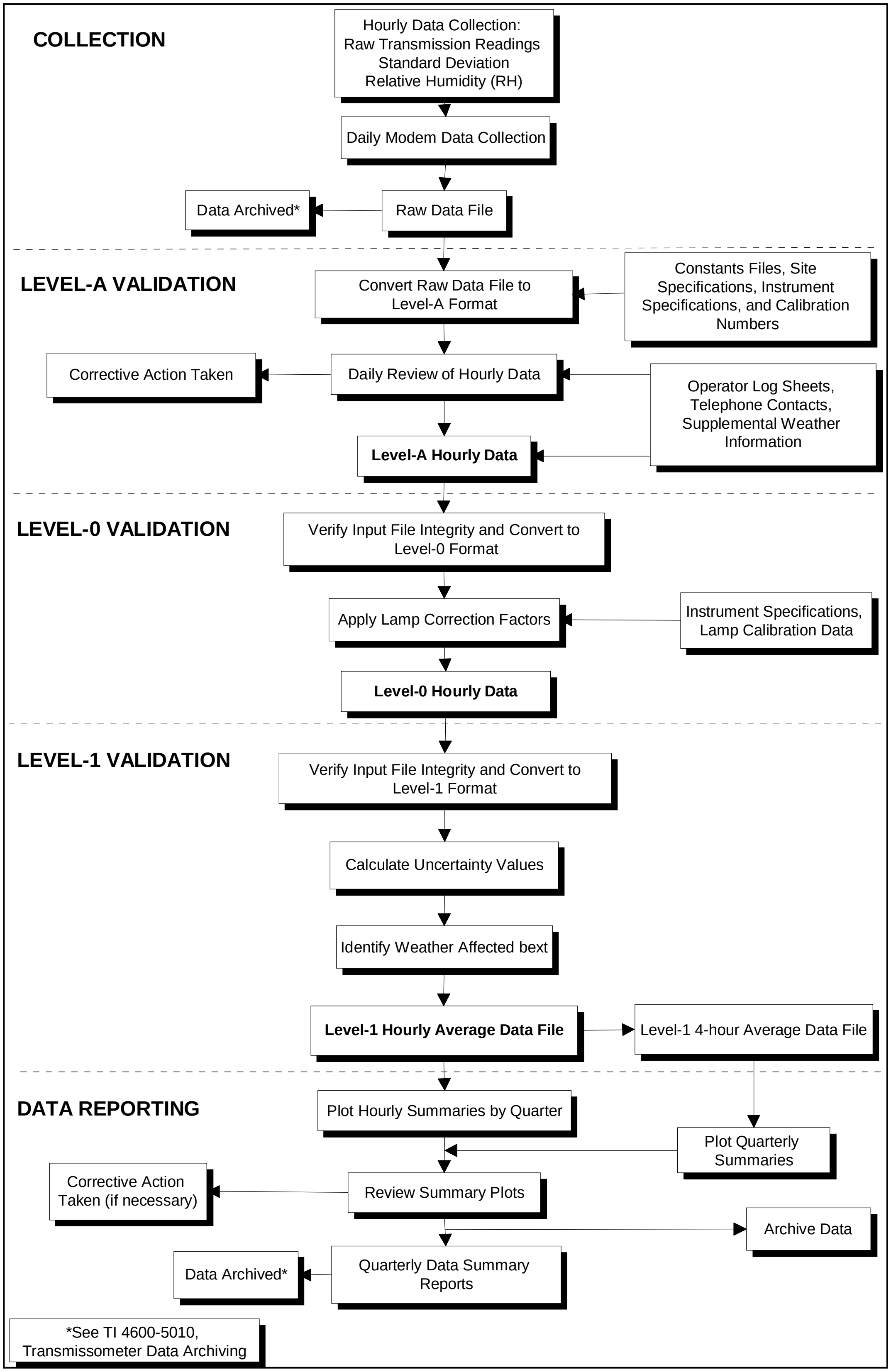


Figure 4-2. Transmissometer Data Processing Flowchart.

<u>Line No.</u> <u>Contents of xxxxx_C File</u>

```
1     GRAND CANYON NATIONAL PARK (SOUTH RIM, GRCA)  UPDATE:  9/08/03
2     CODE DESCRIPTION FILE
3
4
5     START   START   START   START    START   END     END    END      END
6     YEAR    MONTH   DAY     JULIAN   TIME    MONTH   DAY    JULIAN   TIME    CODE    COMMENT
7                             DATE                            DATE
8     - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
9     1996,   12,     1,      335,     0,      12,     17,    351,     0,      8,
10    1996,   12,     18,     352,     21,     12,     21,    355,     16,     1,      FLIP MIRROR
11    1996,   12,     28,     362,     2,      12,     31,    365,     6,      1,
12    1996,   12,     31,     365,     7,      12,     31,    365,     23,     8,
13    1997,   1,      1,      1,       0,      1,      3,     3,       12,     8,
14    1997,   1,      6,      6,       19,     1,      9,     9,       15,     1,
15    1997,   1,      23,     23,      13,     1,      24,    24,      12,     2,      POWER OUTAGE
16    1997,   2,      18,     49,      22,     2,      19,    50,      0,      8,
```

<u>Line Number</u>	<u>Description</u>
1	Site name - Date this file was last updated
2	Information
3	Blank
4	Blank
5-8	Headers
9-xx	Data code information

<u>Field</u>	
START YEAR	Year containing data to be coded invalid
START MONTH	Beginning month containing data to be coded invalid
START DAY	Beginning day for data to be coded invalid
START JULIAN DATE	Beginning Julian date for data to be coded invalid
START TIME	Beginning hour (24-hour format) of data to be coded invalid
END MONTH	Ending month for data to be coded invalid
END DAY	Ending day for data to be coded invalid
END JULIAN DATE	Ending Julian date for data to be coded invalid
END TIME	Ending hour (24-hour format) of data to be coded invalid
CODE	Code indicating reason for data to be coded invalid *
COMMENT	Comment concerning this line in the file

Important: The fields must be separated by a comma! (No commas in the comment field).

* Refer to description of transmissometer validity codes (page 8)

Figure 4-3. Example Code File (xxxxx_C).

Once the site-specific lamp files, code files, and the processing file are all updated with the most current information available regarding lamps, instrument and support equipment operation, and calibration parameters, quarterly processing can be initiated.

EXECUTE PROCESSING SOFTWARE

Level-A processing software (LPV_seas.exe) performs the following functions for each site:

- Generates Level-A formatted quarterly data files, which include only the data records for the quarter to be processed.
- Recalculates b_{ext} from the raw readings, using calibration information in the lamp files.
- Removes periods in the raw file when the b_{ext} exceeds a number of consecutive times specified. In effect, this removes periods of constant b_{ext}.
- Adds codes specified in the code files to the raw files. This saves time from entering long strings of codes manually.

MANUALLY ADD CODES

Transmissometer validity codes reflecting instrument operation can be manually added to the Level-A quarterly files. These can be obtained from reviewing operator log sheets or other operator communications. Transmissometer validity codes used at this level include:

0 = Valid
1 = Invalid: Instrument malfunction
2 = Invalid: System malfunctioned or was removed
6 = Valid: b_{ext} data exceeds maximum (overrange)
8 = Missing: Data acquisition error
9 = Valid: b_{ext} data below Rayleigh (underrange)
A = Invalid: Misalignment
L = Invalid: Defective lamp
S = Invalid: Suspect data
W = Invalid: Unclean optics

A -99 in any data field indicates missing or invalid data.

The maximum b_{ext} occurs when the transmittance falls below 5%. See Appendix A for the calculation used.

4.3.2 Level-0 Validation

Data and validity codes at Level-0 validation are checked for inconsistencies using an internal screening program. The same validity codes used at Level-A apply at Level-0.

EXECUTE PROCESSING SOFTWARE

Level-0 processing software (LPV_seas.exe) performs the following functions for each site:

- Generates Level-0 formatted quarterly data files, which include only the data records for the quarter to be processed.
- Corrects b_{ext} data for lamp drift. This value is based on the calculated average drift of a number of lamps. The algorithm for calculating the drift-related offset applied to each b_{ext} value is discussed in Appendix A.

GENERATE T1 AND T1W FILES

Generates Level-1 formatted data files (*xxxxx*_T11.*yyq*, the hourly average file; and the *xxxxx*_T1W.*yyq*, the hourly average file with weather affected and validity interference codes). These files include only the data records for the quarter to be processed.

4.3.3 Level-1 Validation

Level-1 validation includes two processing steps:

- Calculation of uncertainty values for all data
- Identification of b_{ext} values affected by weather or optical interferences

A key to the Level-1 data file, including validity codes for b_{ext} data, is presented as Figure 4-4.

RUN PROCESSING SOFTWARE

The Level-1 processing software (LPV_seas.exe) is used to again check all data and validity codes for inconsistencies. The data are then reduced to four-hour average values of extinction (b_{ext}), standard visual range (SVR), and haziness (dv). The time periods of the four-hour average values are:

03:00	0000 – 0359 hours
07:00	0400 – 0759 hours
11:00	0800 – 1159 hours
15:00	1200 – 1559 hours
19:00	1600 – 1959 hours
23:00	2000 – 2359 hours

The four-hour average b_{ext} and average dv, along with the average relative humidity, average temperature, and the transmissometer validity code are recorded and kept in the database.

Sample file headers and 6 data records

```
APPEND_T:  1.5:08-17-2000 12-01-2000 08:33:18------------------------------------------
LEVEL0_T:  1.6:12-22-2000 01-15-2001 06:22:03------------------------------------------
LEVEL1_T:  1.6:12-22-2000 01-15-2001 06:22:09------------------------------------------
WX_T:      12-22-2000 01-15-2001 06:22:23 RH Cutoff =  90------------------------------
---------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------
---------------------------------------------------------------------------------------


SITE   YYYYMMDD   JD HHMM INST LAMP BEXT   UC  #  #   UT   DT MAX V A   AT   U  C  RH  U  C  DV

BIBE2 20000901 245  000  004 2159   34   2  1  0  18   10 635 0     28   1  0  36  5  0 122
BIBE2 20000901 245  100  004 2159   36   2  1  0  18   10 635 0     27   1  0  38  5  0 128
BIBE2 20000901 245  200  004 2159   35   1  1  0  18   10 635 0     27   1  0  39  5  0 125
BIBE2 20000901 245  300  004 2159   35   1  1  0  18   10 635 0     27   1  0  39  5  0 125
BIBE2 20000901 245  400  004 2159   33   2  1  0  18   10 635 0     26   1  0  41  5  0 119
BIBE2 20000901 245  500  004 2159   35   2  1  0  18   10 635 0     26   1  0  43  5  0 125
```

Field	**Description**
SITE	Site abbreviation
YYYYMMDD	Date (4-digit year/month/day)
JD	Julian Date
HHMM	Time using a 24-hour clock in hour/minute format
INST	Transmissometer serial number
LAMP	Lamp serial number
BEXT	b_{ext} (Mm^{-1})
UC	b_{ext} uncertainty (Mm^{-1})
#	Number of readings in average
#	Number of readings not in average due to weather
UT	Uncertainty threshold (Mm^{-1})
DT	Δ threshold (Mm^{-1})
MAX	Maximum threshold (Mm^{-1})
V	b_{ext} validity code (0 = valid, 1 = interference, 2 = invalid, 9 = suspect)
A	b_{ext} validity interference subcode[1]
AT	Temperature (°C)
U	Temperature uncertainty (°C)
C	Temperature validity code
RH	Relative humidity (%)
U	Relative humidity uncertainty (%)
C	Relative humidity validity code (0 = valid, 2 = invalid, 9 = suspect)
DV	Haziness (dv x 10)

[1] **b_{ext} Validity Interference Codes:**

Condition	Letter Code A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
RH > RH threshold	x		x		x		x		x		x		x		x
b_{ext} > maximum b_{ext} threshold		x	x			x	x			x	x			x	x
b_{ext} uncertainty > uncertainty threshold				x	x	x	x					x	x	x	x
Δb_{ext} > delta threshold								x	x	x	x	x	x	x	x

Z Weather observation between two other weather observations.

Threshold values may be different for each site.

A -99 in any data field indicates missing or invalid data.

Figure 4-4. Key to the Level-1 Validated Transmissometer Data File.

CALCULATION OF UNCERTAINTIES	The processing software automatically runs the data through a series of transmissometer-related uncertainties. A complete discussion and calculations used are presented in Appendix A.
IDENTIFICATION OF METEOROLOGICAL AND OPTICAL INTERFERENCES	The processing software automatically runs the data through a series of tests, to identify meteorological or optical interferences that affect the calculation of b_{ext} from transmittance measurements. A complete discussion of these tests is presented in Appendix B.

4.3.3.1 Quarterly Summary Plots

Level-1 validated transmissometer and relative humidity data are summarized in quarterly summary plots. Figure 4-5 shows an example quarterly summary plot. The plots are described in detail below:

- **4-Hour Average Variation in Visual Air Quality (Excluding Weather-Affected Data)**
  Timeline of 4-hour average extinction data excluding data affected by weather. The data are plotted as b_{ext} (Mm^{-1}), standard visual range (SVR), and deciview (dv).

- **Relative Humidity**
  Timeline of hourly relative humidity. Note that periods of high extinction are often associated with periods of high relative humidity.

- **Frequency of Occurrence and Cumulative Frequency Summary**
  Frequency of occurrence distribution of hourly extinction data, both including and excluding weather-affected data. The 10% to 90% values are plotted in 10% increments and are summarized in the table next to the plot. The 50% values represent the median of the valid hourly averages.

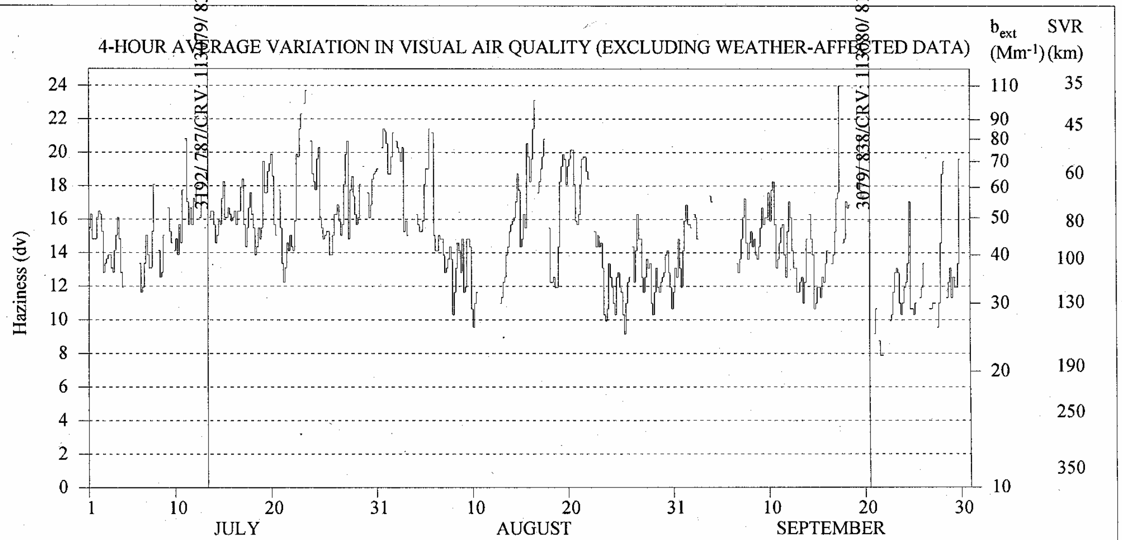
- **Visibility Metric**
  Visibility statistics for data (excluding weather-affected data), including:
  - Mean of the cleanest 20% of valid data
  - Mean of all valid data
  - Mean of the dirtiest 20% of valid data

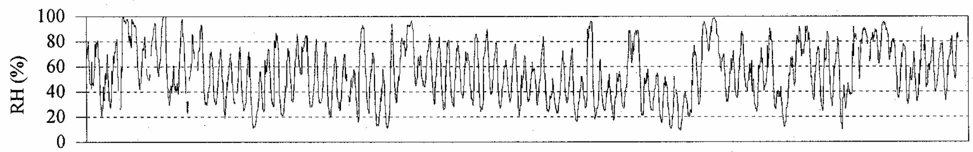
- **Transmissometer Data Recovery**
  Data collection statistics, including:
  - Total number of hourly averages possible in the period
  - Number of valid hourly averages including weather-affected data
  - Number of valid hourly averages excluding weather-affected data
  - Percent of all valid hourly averages not affected by weather

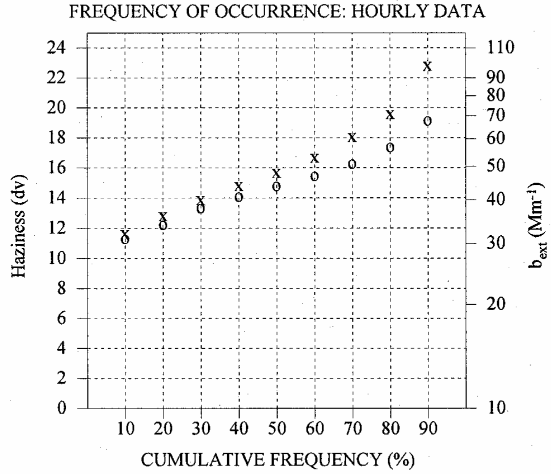
BADLANDS NATIONAL PARK, SOUTH DAKOTA

Transmissometer Data Summary

Summer Quarter: July 1, 2004 - September 30, 2004







CUMULATIVE FREQUENCY SUMMARY

%	Excluding Weather [o] dv	Excluding Weather [o] b_{ext}	Excluding Weather [o] SVR	Including Weather [x] dv	Including Weather [x] b_{ext}	Including Weather [x] SVR
10	11.3	31	129	11.6	32	125
20	12.2	34	117	12.8	36	111
30	13.4	38	105	13.9	40	99
40	14.1	41	97	14.8	44	90
50	14.8	44	90	15.7	48	83
60	15.5	47	84	16.7	53	75
70	16.3	51	78	18.1	61	65
80	17.4	57	69	19.6	71	56
90	19.2	68	58	22.8	98	40

VISIBILITY METRIC (EXCLUDING WEATHER)

	dv	b_{ext}	SVR
Mean of cleanest 20%	11.1	30	133
Mean of all data	15.0	47	93
Mean of dirtiest 20%	19.4	70	57

TRANSMISSOMETER DATA RECOVERY	NUM	%
Total Possible Hourly Averages In The Time Period	2208	100
Valid Hourly Averages Including Weather-Affected Data	2061	93
Valid Hourly Averages Excluding Weather-Affected Data	1494	68
Percent Of All Valid Hourly Averages Not Affected By Weather		72

L:09/22/04 T:09/16/03 W:10/14/04 1:14 p P:11/10/04 V5.02:10/10/2000

Figure 4-5. Example Level-1 Quarterly Summary Plot.

Quarterly summary plots are generated using the LPV_tsum.exe software. The following procedures describe the operation of the LPV_Tsum software:

EXECUTE SOFTWARE

Execute the LPV_tsum software from the Windows Program Manager. The LPV_tsum display will appear as shown in Figure 4-6.

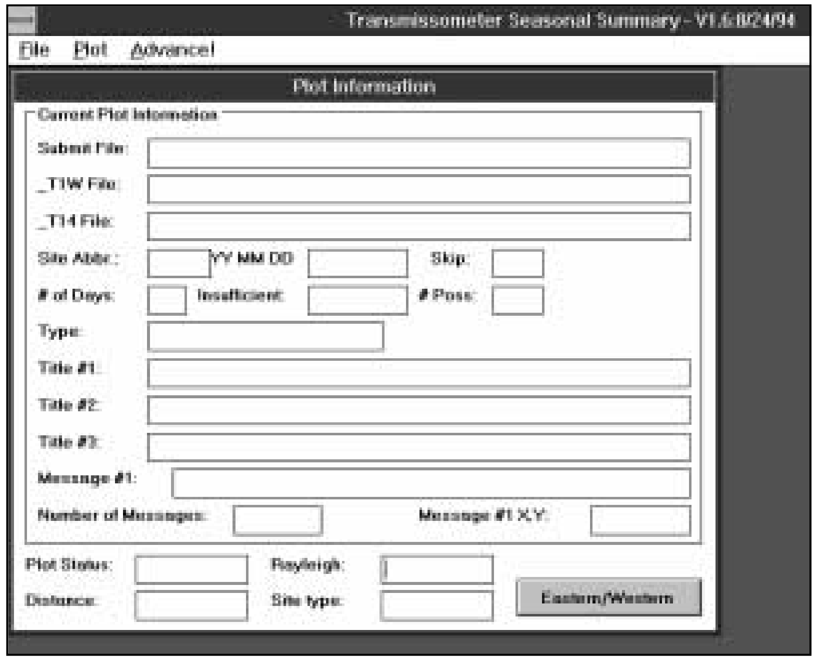


Figure 4-6. LPV_tsum Software Display.

EDIT THE SUBMIT FILE

The submit file defines the Level-1 validated data files and associated parameters used to generate the plots. Figure 4-7 details the format of the submit file. The following procedures are used to edit the submit file:

- Select **Edit Submit File** from the File Menu. The Windows Notepad program will initiate.
- Open an existing submit file or create a new one in Notepad.
- Save the submit file and exit Notepad.

```
BADL_T1W.043                                          Level-1 validated file
BADL_T14.043                                      Level-1 validated file
BADL1                                             Site code
2004,71                                           Year, month, and day of start of plot
92                                                Number of days to read from file
0                                                 Number possible hours, 0=all
2                                                 Plot type, 0 = final, 2 = preliminary
BADLANDS NATIONAL PARK, SOUTH DAKOTA              Main title
Transmissometer Data Summary                      Second title
Summer Quarter:  July 1, 2004 – September 30, 2004   Third title
                                                  PDF file path and name. Leave blank if not using PDF.
                                                  Page number. Leave blank if no page number.
-99                                               Location of page # in inches from bottom. (-99 = no page
                                                                                             #)
12                                                Font size of page number in points.
                                                  Timeline plot comment.
-99, -99                                          Location of comment from lower left.
BAND_T1W.043                                          Next site ...
BAND_T14.043
BAND1
2004, 7, 1
92
0
2
BANDELIER NATIONAL MONUMENT, NEW MEXICO
Transmissometer Data Summary
Summer Quarter: July 1, 2004  - September 30, 2004


-99
12

-99, -99
```

Figure 4-7. Example Submit File for LPV_tsum Quarterly Summary Plot Software.

GENERATE THE PLOTS

The plots defined in the submit file can be plotted to the screen or to any Windows-compatible printer attached to the system. The following procedures are used to generate the plots:

- Select **Submit File** from the File Menu. Select the submit file to use from the file selection box.

- Generate the plots defined in the submit file by clicking **Plot** and then **Plot All Plots**.

REVIEW PLOTS

Quarterly summary plots of Level-1 validated data are reviewed by the data analysts and project manager to identify:

- Data reduction and validation errors
- Instrument operational problems
- Lamp or calibration problems

Problems identified in the Level-1 quarterly summary plot review are resolved by editing the lamp, code, and/or constants files to identify additional valid or invalid data and performing the Level-0 and Level-1 validation procedures again.

When the Level-1 quarterly summary plots have passed the review process, the raw through Level-1 validated data and associated lamp, code, and constants files are archived. (Refer to TI 4600-5010, *Transmissometer Data Archiving (IMPROVE Protocol*).

APPENDIX A

INTERNAL CALCULATIONS USED IN TRANSMISSOMETER DATA VALIDATION AND PROCESSING

A.1 LEVEL-A VALIDATION

The maximum $b_{ext,max}$ occurs when the transmittance falls below 5%. The $b_{ext,max}$ is calculated when data are appended using:

$$b_{ext,\max} = \frac{-\ln(0.05)}{r} \tag{1}$$

Where r = path distance.

A.2 LEVEL-0 VALIDATION

All b_{ext} data are corrected for lamp drift. This value is based on the calculated average drift of a number of lamps. The algorithm for calculating the drift-related offset applied to each b_{ext} value is:

Let t_1 = 16 (number of minutes per hour the lamp is on)
t_2 = 60 (number of minutes in an hour)
t_3 = number of lamp-on hours for the current lamp
L = number of hours the lamp resides in the transmitter
r = path length

The lamp-on time (t_3) for the current lamp is:

$$t_3 = L * t_1 / t_2 \tag{2}$$

The lamp drift correction factor (F_{drift}) is a function of the lamp-on hours (t_3) defined by the following curve for Olympus lamps operating at a nominal voltage of 5.9 VDC:

$$F_{drift}(\%) = 0.270 * t_3^{\,0.4405} \tag{3}$$

The lamp drift corrected transmittance (T_{corr}) is:

$$T_{corr} = [1 + (Fdrift/100)] * T \tag{4}$$

Where T is the measured transmittance. The drift corrected b_{ext} is:

$$b_{ext,corr} = -\ln\left(\frac{1}{T_{corr}}\right) / r \tag{5}$$

Where r is the path distance.

A.3 LEVEL-1 VALIDATION

Calculation of uncertainties at this validation level are discussed below.

TRANSMISSOMETER UNCERTAINTIES

Operationally, the basic equation used to calculate path transmittance in the network is:

$$T = I_r / (F_{lamp} * I_{cal}) \quad (6)$$

where:

T	=	Transmittance of atmosphere of path r
Ir	=	Intensity of light measured at r
I_{cal}	=	Calibration value of transmissometer
F_{lamp}	=	Variability function of lamp output

The relative uncertainty (U_x) of any measured parameter x is defined as:

$$U_x = \sigma_x / \bar{x} \quad (7)$$

where:

$\bar{x}$ = arithmetic mean of all x measurements

δ_x = precision of measurements x defined as

$$\sigma_x = \left[\frac{1}{n-1} \sum_{i=1}^{n} (x_i - \bar{x})^2 \right]^{1/2} \quad (8)$$

Using propagation of error analysis, the relative uncertainty of the path transmittance can be calculated from the relative uncertainties of the measured variables as:

$$U_T = \left(U_{Ir}^{\ 2} + U_{Ical}^{\ 2} + U_{lamp}^{\ 2} \right)^{1/2} \quad (9)$$

where:

U_T	=	relative uncertainty of T
U_{Ir}	=	relative uncertainty of I_r
U_{Ical}	=	relative uncertainty of I_{cal}
U_{lamp}	=	relative uncertainty of F_{lamp}

TRANSMISSOMETER UNCERTAINTIES (continued)

To understand the uncertainty of a transmittance measurement requires a thorough investigation of the precision of each of the following:

- Precision in calibration to determine I_{cal}
- Precision in the measurement of I_r
- Precision in the measurement of F_{lamp}

RELATIVE UNCERTAINTY OF I_{CAL}

The precision in calibration value I_{cal} can be determined by investigating the calibration equation. I_{cal} is the value that would be measured by the transmissometer detector if the atmospheric path was a vacuum. I_{cal} incorporates the path distance r, transmittance of all windows in the path, and size of working aperture used. I_{cal} is determined from:

$$I_{cal} = (CP / WP)^2 * (WG / CG) * (WA / CA)^2 * WT * (1 / FT) * (1 / T) * CR \qquad (10)$$

Using propagation of uncertainty analysis, the relative uncertainty in I_{cal} can be shown to be:

$$U_{cal} = \left(2U^2{}_{CP} + 2U^2{}_{WP} + U^2{}_{CG} + 2U^2{}_{WA} + 2U^2{}_{CA} + U^2{}_{WT} + U^2{}_{FT} + U^2{}_{CR}\right)^{1/2} \qquad (11)$$

Path distances are measured using a laser range finder. Calibration apertures are measured with a precision micrometer. Gain settings are measured with a precision voltmeter. Window and neutral density filter (NDF) transmittances are measured with a reference transmissometer by differencing techniques, thus they do not require absolute calibration. The standard deviation of the raw readings (CR) are calculated at each calibration. The typical working values, measurement precision, and relative uncertainties of these values are:

	Parameter	Value	Precision	Relative Uncertainty
CP	Calibration Path	0.3 km	1×10^{-6} km	3.3×10^{-6}
WP	Working Path	5.0 km	1×10^{-6} km	2.0×10^{-7}
CG	Calibration Gain	100	1×10^{-2}	1.0×10^{-4}
WG	Working Gain	500	1×10^{-2}	2.0×10^{-5}
CA	Calibration Aperture	100 mm	1×10^{-2} mm	1.0×10^{-4}
WA	Working Aperture	110 mm	1×10^{-2} mm	9.1×10^{-5}
WT	Window Transmittance	0.810	0.001	1.2×10^{-3}
FT	NDF Transmittance	0.274	-0.001	3.6×10^{-3}
T	CP Transmittance	0.975	0.003	3.1×10^{-3}
CR	Raw Readings	900	2.0	2.2×10^{-3}

Combining the above values into the uncertainty equation leads to a typical relative uncertainty for I_{cal}: $U_{Ical} = 0.005$.

RELATIVE UNCERTAINTY OF I_R

Under ambient operating conditions the irradiance measured by the transmissometer receiver will fluctuate due to:

- Atmospheric optical turbulence causing scintillation
- Atmospheric optical aberrations causing beam wander
- Varying meteorological conditions along the path: rain, snow, fog
- Insect swarms causing beam interference

The precision of each 10-minute irradiance measurement is calculated by the receiver computer as the standard deviation of the ten 1-minute average irradiance measurements. The measured standard deviation is a direct estimation of atmospheric optical interference. Typical values of I_r and various operational precision estimates that have been observed in the monitoring network are listed below.

Ambient Extinction (km^{-1})	Ir Value	No Optical Interference		Optical Interference	
		Precision	Relative Uncertainty	Precision	Relative Uncertainty
0.010	200	1	0.0050	20	0.100
0.020	190	1	0.0053	20	0.105
0.030	180	1	0.0056	20	0.111
0.050	163	1	0.0061	20	0.123
0.100	127	1	0.0079	20	0.158
0.500	17	1	0.0580	20	1.117

Working Path = 5.0 km, $I_{cal} = 210$

As can be seen for the relative uncertainty of the measured intensity is a function of the extinction of the path. For typical extinction measurements free from optical interference in the network, the average relative uncertainty in I_r is approximately: $U_{Ir} = 0.0055$.

RELATIVE UNCERTAINTY OF F_{LAMP}

The major source of uncertainty in the transmissometer data is lamp drift correction. The transmitter employs an optical feedback loop designed to maintain constant irradiance within the 10nm bandwidth of the receiver filter/detector module. However, comparison of pre- and post-lamp calibrations show that the transmitter lamp output increases (brightens) with increased hours of lamp use. Tests have shown that the brightening is definitely a function of the lamp rather than the feedback circuit or filter. It is important to note that a 1% increase in irradiance over a path length of approximately five kilometers (the Grand Canyon sight path for example) results in the apparent extinction being decreased by 0.002 km^{-1} (20% of Rayleigh!!); i.e., the instrument measurement indicates the air to be cleaner than it actually is.

RELATIVE UNCERTAINTY OF F_{LAMP} (continued)

The method initially used to handle this bias was to compare the pre- and post-lamp calibrations and generate a lamp brightening factor that would be applied to the raw irradiance prior to calculating path transmittance. Early results from 1987 suggested a fairly stable 2% per 500 hour brightening rate through the first 500 hours of lamp use. Site operator lamp changes were scheduled at three-month intervals (approximately 575 hours of lamp “on” time). The systems were returned to Fort Collins annually for routine servicing. Prior to servicing the instrument, lamp brightening would be verified by post-calibrating all lamps. This method resulted in delays of over a year before final data were available. Additionally, due to instrument failure, instrument damage, or lamp breakage, it is not always possible to post-calibrate all lamps used operationally. Therefore, a constant 2% per 500 hours correction factor was applied to all lamps to facilitate data collection, processing, and reporting. This lamp drift correction factor was based on post-calibrations of the first 10 lamps from the three systems used in the WHITEX study.

During 1992, a re-examination of all available post-calibration data showed that the lamp brightening factors were not as well-behaved as early post-calibrations had indicated. In January 1993, development of revised processing procedures that more accurately estimate transmissometer lamp drift correction was completed. Lamp brightening percentages and lamp “on” hours for all systems and lamps post-calibrated at t he Fort Collins, Colorado, transmissometer calibration facility are entered into a lamp brightening database. The data in this database are used to create statistics on lamp brightening. Lamp brightening percentages for post-calibrated lamps are sorted into time bins based on lamp operational hours. The mean and standard deviation of operational hours and percent lamp brightening were calculated for each bin. Power law functions are fitted to these data to define a statistically based mean lamp brightening and the one sigma upper and lower bounds. Applying the mean function to the raw transmissometer irradiance readings corrects for lamp brightening. The precision of the correction is calculated from the upper and lower bounds for the number of hours on the lamp at the time of the reading.

If, upon post-calibration, a system exhibits abnormally high or low lamp brightening, previously reported extinction data are flagged for further review. The lamp brightening database is continually updated as additional lamps are post-calibrated. Periodically, the lamp brightening statistics are reanalyzed to provide a more accurate description of the lamp drift correction and the precision associated with this correction.

RELATIVE UNCERTAINTY OF F_{LAMP} (continued)

Variations in lamp brightening characteristics for a given lamp design may occur due to variations in manufacturing processes between manufacturers. All lamps used with the LPV-2 transmissometer are purchased from the transmissometer manufacturer, Optec, inc. Optec purchases standard lamps from the lamp manufacturer and precisely aligned the filament of each lamp prior to delivering the lamps for operational use. From 1986 through March 1993, all lamps supplied by Optec were purchased from Micro-Optics, Inc. Beginning in April 1993, lamps supplied by Optec have been purchased through a new distributor, Lamp Technology, Inc. These lamps are manufactured by Olympus and are considered to be of higher quality than the Micro-Optics lamps. A second factor that influences lamp brightening is the lamp operating voltage. Prior to 1990, IMPROVE operating procedures specified a nominal lamp operating voltage of 5.6 VDC. In 1990, the nominal lamp operating voltages was increased to 5.9 VDC. As a result of these changes, all operational lamps were placed in one of the following three categories:

- Low voltage Micro-Optic lamps, 5.6 VDC (1986 – 1989)
- High voltage Micro-Optic lamps, 5.9 VDC (1990 – March 1993)
- High voltage Olympus lamps, 5.9 VDC (April 1993 – present)

Using the revised processing procedures described above, statistically-based lamp brightening functions were derived from post-calibration data for lamps in each of these three operational categories.

<u>Low Voltage Micro-Optic Lamps (1986 – 1989)</u>

Figure A-1 is an analysis of lamp brightening data for Micro-Optic lamps pre-calibrated prior to 1990. These lamps were calibrated for a nominal operating voltage of 5.6 VDC. For low voltage lamps, the lamp drift correction applied for the first 500 hours of accumulated lamp time is a linear approximation to the mean brightening curve of Figure A-1 (3.08% per 500 hours). Beyond 500 hours, the lamp drift correction is a constant offset equal to the correction at 500 hours (3.08%). The precision of the brightening measurements for the low voltage lamps has been approximately 3.1%. The relative uncertainty in F_{lamp} for a low voltage lamp at 500 hours is: $U_{lamp} = 0.030$.

RELATIVE UNCERTAINTY OF F_{LAMP} (continued)

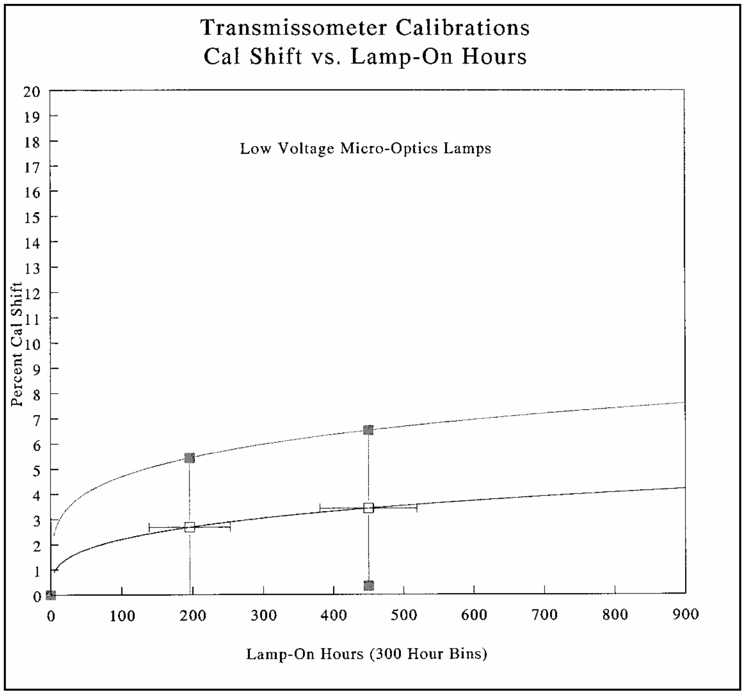


Figure A-1. Lamp Brightening Curve – Low Voltage Micro-Optics Lamps.

High Voltage Micro-Optic Lamps (1990 – March 1993)

In early 1990, the nominal lamp operating voltage was increased to 5.9 VDC. An analysis of the lamp brightening data for Micro-Optics lamps calibrated at this higher operating voltage is presented in Figure A-2. For these lamps, the lamp drift correction applied during the first 700 hours of accumulated lamp time follows the mean brightening curve of Figure A-2. The equation for calculating lamp brightening using this curve is:

$$LampBrightening(\%) = a_o * t^{a_1} \qquad (12)$$

where:

t = accumulated lamp “on” time (hours
a_0 = 0.0585
a_1 = 0.6849

Beyond 700 hours, the lamp drift correction is constant at the 700 hour value (5.19%). The precision of the brightening measurements for the high voltage Micro-Optics lamps has been approximately 2.7%. The relative uncertainty in F_{lamp} for a high voltage lamp at 500 hours is: $U_{lamp} = 0.026$.

RELATIVE UNCERTAINTY OF F_{LAMP} (continued)

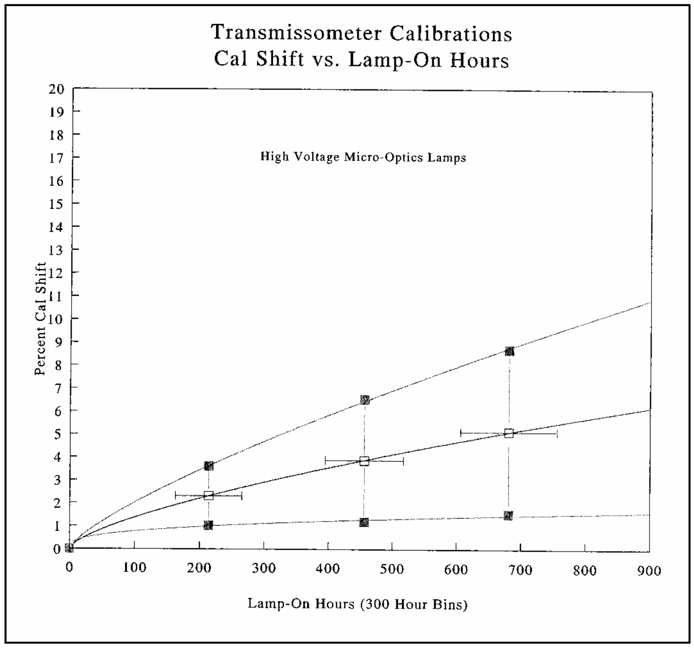


Figure A-2. Lamp Brightening Curve – High Voltage Micro-Optics Lamps.

High Voltage Olympus Lamps (April 1993 - Present)

Beginning in April 1993, all replacement lamps calibrated for use in the IMPROVE network have been Olympus lamps with a nominal operating voltage of 5.9 VDC. Figure A-3 is an analysis of lamp brightening data for the post-calibrated Olympus lamps. The lamp drift correction for the Olympus lamps follows the mean brightening curve of Figure A-3. The equation for calculating lamp brightening is of the same form as the equation given for the high voltage Micro-Optic lamp (Equation 12) with:

t = accumulated lamp "on" time (hours)
a_0 = 0.2700
a_1 = 0.4405

Current IMPROVE network operations procedures specify that eight (8) pre-calibrated lamps be provided with each replacement transmissometer installed during an annual site servicing visit. This permits lamp changeouts at two-month intervals, ensuring that operational lamps will generally accumulate less than 500 hours of "on" time. Therefore, a separate high-hours lamp drift correction is not required.

Until additional Olympus lamps have been post-calibrated, the relative uncertainty in F_{lamp} calculated for the high voltage Micro-Optics lamps will also be used with the high voltage Olympus lamps ($U_{lamp} = 0.026$).

RELATIVE UNCERTAINTY OF F_{LAMP} (continued)

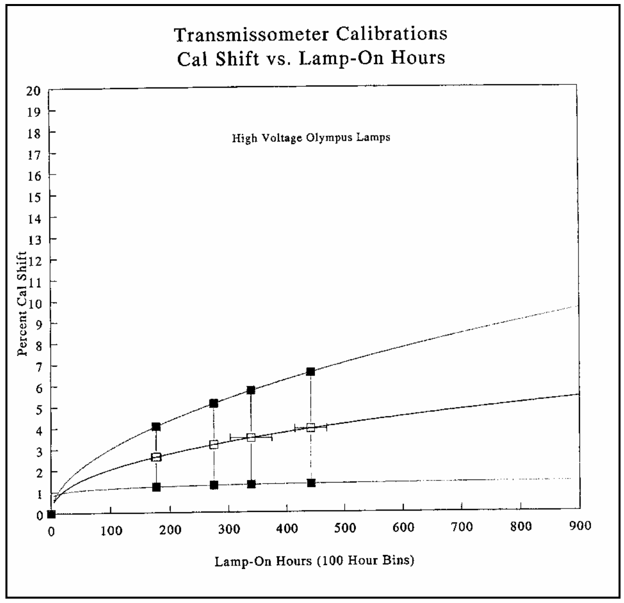


Figure A-3. Lamp Brightening Curve – High Voltage Olympus Lamps.

RELATIVE UNCERTAINTY IN PATH TRANSMITTANCE

From the above analysis, the relative uncertainty in path transmittance can be calculated for each 10-minute transmittance measurement by the transmissometer. The typical values are:

Condition	Relative Uncertainty (U_T)
No Optical Interference	0.02
Optical Interference	0.20

PRECISION OF EXTINCTION ESTIMATES FROM TRANSMITTANCE MEASUREMENTS

The average extinction b_{ext} of the transmissometer optical path (r) is calculated from the transmittance measurement (T) by:

$$b_{ext} = -\ln(T)/r \tag{13}$$

Since the path length r is measured to an extremely high precision, the precision in b_{ext} can be approximated from propagation of error analysis as:

$$\sigma_{bext} = \pm U_T / r \tag{14}$$

The relative uncertainty in transmittance leads to an additive uncertainty in extinction that depends on the path length of the transmittance measurement. Table A-1 lists the average uncertainty of b_{ext} estimates for typical sight paths in the monitoring network when no optical interferences are present along the path.

PRECISION OF EXTINCTION ESTIMATES FROM TRANSMITTANCE MEASUREMENTS (continued)

Table A-1

Typical Uncertainty in b_{ext}
for Selected Monitoring Locations

Location	Path (km)	Precision (km^{-1})
Tonto	7.20	0.004
Grand Canyon	5.79	0.005
Acadia	3.67	0.007
Yosemite	2.71	0.100
Shenandoah	0.68	0.398

BIAS IN EXTINCTION CALCULATIONS

The calibration equation assumes clean glass surfaces of constant transmittance. Any change in the window transmittance results in a bias added to the calculated extinction. If the window transmittance decreases the calculated extinction will increase, if it increases, the calculated extinction will decrease. As with the precision, the bias is a function of the relative change in window transmittance and path distance:

$$Bias = (relative\ change\ in\ window\ transmittance)/r \qquad (15)$$

The possibility exists for errors to arise from changes in the transmittance of the windows due to:

- Pitting of the windows by windblown dirt
- Staining of the windows by pollution
- Dirt collecting on the window surface due to dust, rain, snow
- Fogging of the windows at high humidies
- Improper servicing resulting in smudging of the windows
- Removal of the windows due to breakage

National Park Service (NPS) transmissometer data collected during 1991 was used to investigate the bias associated with varying window transmittance. Field operators are instructed to visit both the receiver and transmitter weekly. One of their duties is to observe the windows carefully and clean them regularly. These actions are noted on the field log sheets. The NPS database was scanned to locate the indiciated times when the windows of the transmissometer systems were cleaned. The previous three

BIAS IN EXTINCTION CALCULATIONS (continued)

hours and the following three hours of data were extracted for each cleaning. Servicing periods when the measured irradiance was constant before the windows were cleaned and also remained constant (independent of the previous three hours) after cleaning were identified. Three hundred thirty-five (335) servicings were selected that met these requirements. The average change in window transmittance was calculated from the difference between the mean irradiance values before and after servicing from this data set. The mean change was found to be 0.1%. This is misleading due to the fact that the servicing of the windows can have three possible effects:

- No change in window transmittance – the windows were perfectly clean before and after servicing.
- The window transmittance increased – the windows were dirty and servicing cleaned them.
- The window transmittance decreased – the windows were clean and servicing made them dirty.

The first condition leads to no change in window transmittance, thus no bias. The second condition would indicate that b_{ext} values measured before the servicing were biased too high. The third condition would result in b_{ext} values measured after window cleaning biased too high. Thus, in practice, unless the window is removed or a window with a higher transmittance is substituted, the bias due to a change in window transmittance is in one direction: increasing the calculated extinction either before or after the servicing. If second and third conditions have about the same magnitude and occur at about the same frequency, a simple comparison of mean radiance differences before and after servicing will come out as a zero percent change. Therefore, a better indiciation of this bias is a calculation suing the absolute value of the difference in mean radiances measured before and after servicing. When this is done, the mean change in window transmtittance for the NPS network was 1.5%.

Typical bias estimates in bext for a 1.5% change in window transmittance at selected monitoring locations are listed in Table A-2.

BIAS IN EXTINCTION CALCULATIONS (continued)

Table A-2

Typical Bias in b_{ext} for Selected Monitoring Locations

Location	Path (km)	Bias (km^{-1})
Tonto	7.20	0.002
Grand Canyon	5.79	0.003
Acadia	3.67	0.004
Yosemite	2.71	0.006
Shenandoah	0.68	0.022

AIR TEMPERATURE AND RELATIVE HUMIDITY UNCERTAINTY

The uncertainties and limits for meteorological data collected are obtained from the manufacturer’s literature. The values used are listed below:

U_{temp}	=	1° C
U_{RH}	=	2% (Rotronics MP100F sensor)
Maximum temperature	=	60° C
Minimum temperature	=	-50° C
Maximum relative humidity	=	100%
Minimum relative humidity	=	0%

APPENDIX B

IDENTIFICATION OF METEOROLOGICAL AND OPTICAL INTERFERENCES THAT AFFECT THE CALCULATION OF b_{EXT} FROM TRANSMITTANCE MEASUREMENTS

B.1 METEOROLOGICAL AND OPTICAL INTERFERENCES

The transmissometer directly measures the irradiance of a light source after the light has traveled over a finite atmospheric path. The average extinction coefficient of the sight path is calculated from this measurement and is attributed to the average concentration of atmospheric gases and ambient aerosols along the sight path. The intensity of the light, however, can be modified not only by intervening gases and aerosols, but also by:

- The presence of condensed water vapor in the form of fog, clouds, and precipitation along the sight path.
- Condensation, frost, snow, or ice on the shelter windows.
- Reduction in light intensity by insects, birds, animals, or vegetation along the sight path, or on the optical surfaces of the instrumentation or shelter windows.
- Fluctuations in light intensity both positive and negative due to optical turbulence, beam wander, atmospheric lensing, and miraging caused by variations in the atmospheric optical index of refraction along the sight path.

A major effort was undertaken to develop an algorithm to identify transmissometer extinction data that may be affected by the interferences described above. This algorithm contains five major tests:

1) Relative Humidity
2) Maximum Extinction
3) Uncertainty Threshold
4) Rate of Change of Extinction
5) Isolated Data Points

Due to the large volume of extinction data collected by transmissometers as compared to aerosol monitors, the algorithm has been designed to be a conservative filter on the extinction data. That is, if an hourly extinction measurement indicates the slightest possibility of meteorological or optical interference by failing any one of the above tests, it is flagged with identifier codes in the Level-1 data file. The following describes each of the five tests:

RELATIVE HUMIDITY

When the relative humidity measured at the transmissometer receiver is greater than 90%, the corresponding transmissometer measurement is flagged as having a possible interference. The 90% level has been chosen due to the following considerations:

- The relative humidity is only measured at the receiver location, and not ant any other position along the sight path.
- A 1.5° C change in dew point temperature results in a 10% change in relative humidity.
- The atmosphere is continuously undergoing both systematic and random variations in its spatial and temporal properties.
- The typical precision of relative humidity measurements is ± 2%.

RELATIVE HUMIDITY (continued)

The above considerations all indicate that inferring a precise knowledge of the meteorological conditions along a sight path at high relative humidity from a single point measurement is very difficult. When the relative humidity is above 90% at one end of the path, small, random temperature or absolute humidity fluctuations along the path can lead to condensation of water vapor causing meteorological interferences. Thus, in accordance with the conservative philosophy expressed above, the 90% relative humidity limit was selected for this test.

MAXIMUM THRESHOLD

For every transmissometer sight path, a maximum b_{ext} can be calculated that corresponds to a 5% transmittance for the path. All sight paths were selected, such that based on historical visibility data, this maximum b_{ext} occurs less than 1% of the time. When the measured b_{ext} is greater than this threshold value, it is assumed that meteorological or optical interferences, not ambient aerosols, are causing the high extinction. All measurements greater than the calculated site-specific maximum threshold are flagged in the data file.

UNCERTAINTY THRESHOLD

The normal operating procedure for the transmissometer is to take ten 1-minute measurements of transmitter irradiance each hour, and report the average and standard deviation of the 10 values. A mean hourly extinction and associated uncertainty is then calculated as described in Section 4.3 from these measurements. In remote, rural areas, the ambient aerosol concentration typically varies quite slowly with time constants on the order of a few hours rather than minutes. This leads to the expectation of relatively constant extinction during the 10 minutes of receiver measurements and a low standard deviation of measured transmitter irradiance. If only 1 of the 10 irradiance values varies more than 20% from the mean, the uncertainty in b_{ext} will increase dramatically. The presence of any meteorological or optical interferences along the sight path will lead to large standard deviations in lamp irradiance, thus large uncertainties in b_{ext}. With the conservative assumption of constant b_{ext} during any 10 minute measurement period, any increase in the uncertainty of b_{ext} above a selected threshold flags the measurement as affected by one of these interferences. The uncertainty threshold is determined for each sight path and is included in each Level-1 data file for reference.

RATE OF CHANGE OF EXTINCTION (DELTA THRESHOLD)

Transmissometer data collected before September 1, 1990, did not include standard deviation of measured irradiance values. For data collected before this date, another test was developed to identify periods of interferences associated with rapidly fluctuating irradiance measurements. This test consists of comparing the hourly average extinction to the preceding and following hours, and calculating a rate of change in each direction. If the absolute value of this rate of change is greater than some assigned Delta threshold, the hourly b_{ext} value is flagged as being affected by interferences. Delta thresholds have been determined for each sight path by analyzing extinction data collected after September 1990, which have corresponding uncertainty thresholds to determine appropriate Delta thresholds for the sight path. The Delta threshold is typically not as low as the uncertainty threshold, due to the possibility of larger hourly variations in b_{ext} as compared to variations during 10 minutes of measurements. Each sight path has its own Delta threshold and it is listed in the Level-1 data file for reference.

ISOLATED DATA POINTS

This test is performed after the above four thresholds are applied to the hourly extinction data. It is used to identify data points that have passed the above thresholds, but are located between hourly b_{ext} data that have failed the above thresholds. The conservative assumption is, if data before and after the isolated hour indicates interferences, the hour in question probably is also affected by interferences. The data is also flagged as weather-affected.

B.2 SUPPLEMENTAL VISIBILITY INDICES

B.2.1 Standard Visual Range

Standard visual range (SVR) can be interpreted as the farthest distance that a large, black feature can be seen on the horizon. It is a useful visibility index that allows for comparison of data taken at various locations.

$$SVR = \frac{3.912}{\left(b_{ext} - b_{ray} + 0.01km^{-1}\right)} \tag{16}$$

SVR is calculated to normalize all visual range to a Rayleigh scattering coefficient of 0.01 km^{-1}, or an altitude of 1.524 km (5,000 ft.). The Rayleigh scattering coefficient, b_{ray}, for the mean sight path altitude is subtracted from the calculated extinction coefficient, b_{ext}, and the standard Rayleigh scattering coefficient of 0.01 km^{-1} is added back. The value 3.912 is the constant derived from assuming a 2% contrast detection threshold. The theoretical maximum SVR is 391 km.

B.2.2 Deciview

An easily understood visibility index has been recently developed to uniformly describe visibility impairment. The scale of this visibility index, expressed in deciview (dv), is linear with respect to perceived visual changes over its entire range, analogous to the decibel scale for sound.

Neither visual range nor extinction coefficient is linear to perceived visual scene changes caused by uniform haze. For example, a 5 km change in visual range or a 0.01 km^{-1} change in extinction coefficient can result in a scene change that is either imperceptible or very obvious, depending on the baseline visibility conditions.

The newly developed visibility index's dv scale is linear to humanly perceived changes in visual air quality. A one dv change is about a 10% change in extinction coefficient, which is a small, but perceptible scenic change under many circumstances. Since the deciview scale is near zero for a pristine atmosphere (dv=0 for Rayleigh conditions at about 1.8 km elevation) and increases as visibility is degraded, it measures perceived haziness. Expressed in terms of extinction coefficient (b_{ext}) and visual range (vr):

$$haziness(dv) = 10\ln\left(\frac{b_{ext}}{0.01km^{-1}}\right) = 10\ln\left(\frac{391km}{vr}\right) \qquad (17)$$

The name deciview was chosen because of the similarity of the decibel scale in acoustics. Both use 10 times the logarithm of a ratio of a measured physical quantity to a reference value to create scales that are approximately linear with respect to changes as perceived by human senses.

Ideally, a just noticeable change (JNC) in scene visibility should be approximately a one or two dv change in the deciview scale (i.e., a 10% to 20% fractional change in extinction coefficient) regardless of the baseline visibility level. Similarly, a change of any specific number of dv should appear to have approximately the same magnitude of visual change on any scene.

The dv scale provides a convenient, numerical method for presentation of visibility values. Any visibility monitoring data that are available in visual range or extinction coefficient area easily converted to the new visibility index expressed in deciview.

Use of the dv scale is an appropriate way to compare and combine data from different visibility perception and valuation studies. When results from multiple studies are presented in terms of a common perception index, the effects of survey approach and other factors influential to the results can be evaluated.