Development of Strategic Highway Research Program Long-Term Pavement Performance Climatic Data Base

S. D. RABINOW, G. R. RADA, S. D. TAYABJI, AND C. A. RICHTER

Although the effects of climatic factors on pavement performance have long been recognized as important, those effects remain largely unquantified because individual pavement research projects to date generally have been restricted to limited geographic areas with more or less uniform climatic conditions and relatively short time spans, making it difficult to separate the effects of climatic factors from those of loading. By virtue of the relatively broad geographic and climatic distribution of the test sections involved and the long-term nature of the study, the Long-Term Pavement Performance (LTPP) program will rectify this situation. The Strategic Highway Research Program (SHRP) climatic data base is intended to provide the weather and climatic information needed to characterize the environment in which each LTPP test section has existed from the time of construction through the LTPP monitoring period. The development of SHRP's LTPP climatic data base, including the identification and sources of data, selection and verification of weather stations, actual data retrieval from available sources, and data quality assurance, is summarized. Future activities, such as updates and expansion of the data base and the collection of ground-truth data, are also discussed.

The Strategic Highway Research Program (SHRP) long-term pavement performance (LTPP) research is a 20-year study to determine pavement performance and the factors that affect it. To meet these goals, two series of experiments were established within the LTPP research program. The General Pavement Studies (GPS) involve test sections on existing pavements, whereas the Specific Pavement Studies (SPS) involve specially constructed pavement test sections. Both sets of test sections are, or will be, located on in-service highways throughout the United States and Canada and hence subjected to "real" nonidealized traffic loadings and a wide range of environmental conditions.

The data to be collected for SHRP LTPP research can be divided into five categories: (a) inventory data describing the location, geometry, and construction history of the test section; (b) monitoring data such as distress, profile, and deflection, which are collected to monitor changes in the pavement over time; (c) traffic data, which describe the loading to which the pavement is subjected; (d) climatic data, describing the environmental conditions to which the pavement is subjected; and (e) maintenance and rehabilitation data, describing and defining any and all maintenance applied to the pavement. This paper focuses on the collection and storage of climatic data for SHRP LTPP test sections.

S. D. Rabinow, G. R. Rada, and S. D. Tayabji, PCS/Law Engineering, 12240 Indian Creek Court, Suite 120, Beltsville, Md. 20705-1242. C. A. Richter, FHWA-LTPP Division, 6300 Georgetown Pike, HNR-40, McLean, Va. 22101-2296.

Although the effects of climatic factors on pavement performance have long been recognized as important, those effects remain largely unquantified because individual pavement research projects to date generally have been restricted to limited geographic areas with more or less uniform climatic conditions and relatively short time spans, making it difficult to separate the effects of climatic factors from those of loading. By virtue of the relatively broad geographic and climatic distribution of the test sections involved, and the long-term nature of the study, the LTPP program will rectify this situation.

Over the past several years, SHRP has mounted an effort to identify, obtain, and store climatic data for LTPP GPS test sections (*1*). This effort culminated in the development of SHRP's LTPP climatic data base, which contains the weather and climatic information needed to characterize the environment in which each GPS test section has existed from the time of construction through the LTPP monitoring period. In this paper the development of the LTPP climatic data base, the actual data collection and quality assurance process, and future activities related to climatic data are reviewed.

Although not discussed in the paper, climatic data, along with other LTPP information, are currently being used by the SHRP analysis contractor to verify and calibrate the existing AASHTO pavement performance models. It is anticipated that in coming years, these data will be used to better quantify the effects of climatic factors on pavement performance, to verify and calibrate other existing performance models, or to develop new ones. In addition, these data conceivably can support an unlimited number of research and development efforts that address the impact of climate on pavement performance.

DATA BASE DEVELOPMENT

Identification of Weather Stations

Details on the development of plans for the collection of climatic data have been documented elsewhere (*1,2*). Those plans centered around the use of National Climatic Data Center (NCDC) and Canadian Climatic Center (CCC) data. Technical direction was provided by SHRP's Environmental Data Expert Task Group (ETG) composed of pavement and weather professionals.

The development of plans began with the definition of a "perfect" weather station: it must be close to the pavement test section and the types of data collected and their accuracy must be equivalent to at least a first-order weather station. Although an attempt to establish proximity guidelines was made, it became apparent from the start (as was expected) that weather stations could not be found close to most SHRP LTPP test sites. Consequently, the plans were developed around the concept that data from up to five nearby weather stations would be used to estimate site-specific climatic conditions, that is, by development of a statistical or "virtual" station.

The choice of five weather stations to represent climatic conditions at a given site was somewhat arbitrary and may yield a misleading impression of data coverage for a given site. In fact, one "good" station is all that is needed for a given site. In terms of the virtual station, an "interpolation" algorithm using a $1/R$ weighting scheme was originally recommended, where R is the distance from the weather station to the site. This scheme was later modified to $1/R^2$ on the basis of the recommendations of the ETG. In any case, the closer the weather station is to the site, the greater its effect is on the calculated values for the virtual station. For example, any weather station three times farther from the GPS site than the closest weather station carries only one-ninth the weight in the calculation of the closest station. Figure 1 shows an example of a GPS site and the five weather stations selected for describing its environmental conditions.

The criteria established for the identification of weather stations in the vicinity of the pavement test section are as follows. For each GPS test site, identify

- At least one active first-order weather station with 50 percent data coverage for the record length to be used (a wider range of data elements is collected by these stations and a higher level of quality assurance is exercised by NCDC on the data);
- The closest active cooperative weather stations that satisfy the following criteria (data elements collected by these stations generally are limited to temperature and precipitation):
  - At least 50 percent data coverage for the record length to be used,
  - Record length at least equal to the pavement age or 5 years after the pavement construction date,
  - The following data elements recorded as a minimum: minimum daily temperature; maximum daily temperature; daily precipitation; and daily snowfall (if applicable); and,
- The three closest active or inactive (with at least part of the record length covering years after the pavement construc-

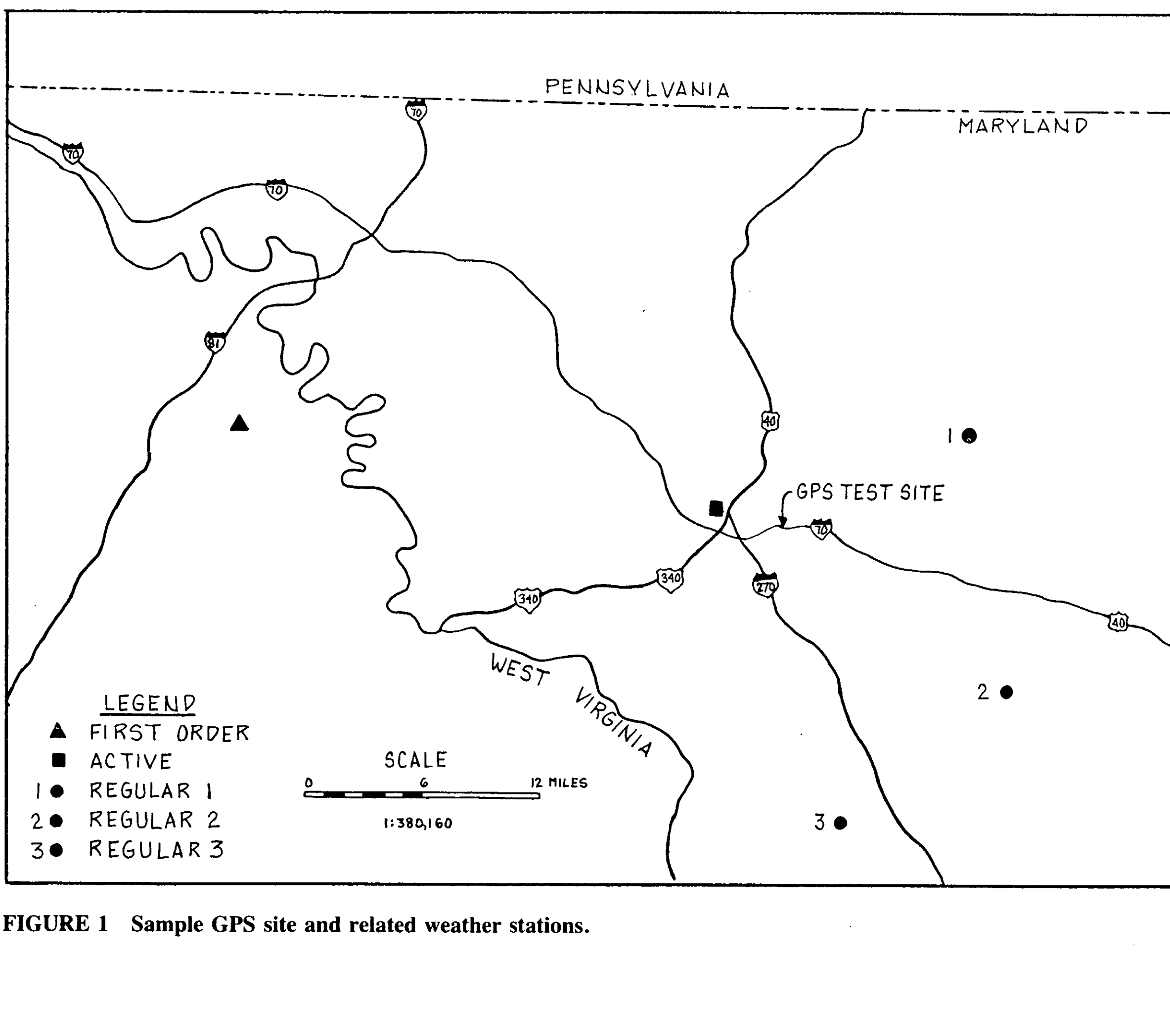

FIGURE 1 Sample GPS site and related weather stations.

tion date), first-order or cooperative weather stations other than those included in the first and second items.

The identification process was to be global—not limited by state or provincial borders to allow the consideration of weather stations close to a site but located in a neighboring state or province.

Climatic Data Elements

On completion of the weather station identification process, the data elements shown in Table 1 were acquired from NCDC and CCC files, where available, for each station. Because of limitations associated with the NCDC data collection procedure, however, only the first six data fields listed in Table 1 are available from cooperative weather stations, and the rest are available only from first-order weather stations. Also, the first five elements in this list generally are available for the entire time span, whereas the remaining eight are predominantly available only after 1984.

In addition, the monthly average, standard deviation, skewness, and kurtosis were determined for all data elements shown in Table 1, except daily occurrences of weather, for each year. The equations used in these computations are summarized below:

$$\bar{x} = \frac{\sum_{i=1}^{n} X_i}{n}$$

$$S^2 = \frac{\sum_{i=1}^{n} (X_i - \bar{x})^2}{n}$$

$$\alpha_3 = \frac{\dfrac{\sum_{i=1}^{n} (X_i - \bar{x})^3}{n}}{S^3}$$

$$\alpha_4 = \frac{\dfrac{\sum_{i=1}^{n} (X_i - \bar{x})^4}{n}}{S^4}$$

where

$\bar{x}$ = monthly average;
S = monthly standard deviation;
α_3 = monthly kurtosis;
α_4 = monthly skewness;
X_i = value of a data element on the ith day; and
n = number of days with records in a month.

Where some daily data were missing, the monthly statistical parameters were to be calculated using the available data only, without substitution for mission data. In addition, the following "derived" data were to be calculated and ultimately stored in the LTPP climatic data base:

- Total monthly precipitation,
- Total monthly snowfall,
- Number of air freeze-thaw cycles (monthly),
- Mean daily temperature range (monthly),
- Number of wet days (precipitation > 0.01 in.),
- Number of high-intensity precipitation days (precipitation > 0.5 in.),
- Air freezing index,
- Number of days with maximum temperatures above 90°F (monthly), and
- Number of days with minimum temperature below 32°F (monthly).

It should be clearly noted that the average monthly values to be stored within the data base were to be average daily values for that parameter for that month. For example, the average precipitation field for a particular month would contain the average daily precipitation for that month.

Of these calculated parameters, only the air freezing index and air freeze-thaw cycles are complex. For the air freezing index, each day's minimum temperature is compared with 32°F (0°C for Canadian GPS sites), and if it is below freezing, the number of degrees below freezing is added to both the current month's air freezing index and the current year's air freezing index. If the daily minimum temperature is missing, the missing data count is incremented for both the monthly count and the yearly count. Air freeze-thaw cycles are calculated by comparing daily minimum (TMIN) and daily maximum (TMAX) temperatures to the freezing point and to each other. Each air freeze-thaw cycle consists of one sequence of a TMIN below freezing followed by a TMAX above freezing followed by a TMIN below freezing.

In addition to the climatic data elements, it was recommended that the following information be stored in the climatic data base to characterize the weather stations: weather station name, number, and type (first order or cooperative); distance from applicable SHRP test site; elevation; bearing with respect to test site; and data coverage for temperature and moisture.

Several other data elements were considered for inclusion in the climatic data base but were rejected for one or more reasons. Thornthwaite moisture index (TMI) was not included because of the lack of pan evaporation data needed to calculate values, and because it was believed that storage of values derived from contour maps, which are widely available, was not warranted.

Another example of a data element initially intended to be included is solar radiation. Solar radiation data were indeed collected by NCDC until 1984 at a few sites. At some point before that date, however, it was discovered that the measured values were highly unreliable, and NCDC terminated their collection. There have been several efforts since that date to correct the collected data, but they have thus far proven ineffective. Consequently, SHRP elected not to store these suspect values.

Climatic Data Base

Once the climatic data elements and sources of information had been established, the last step in the development of the

TABLE 1 Climatic Data Elements

Data Element	NCDC Designation
1. Maximum Daily Temperature	TMAX
2. Minimum Daily Temperature	TMIN
3. Mean Daily Temperature	MNTP
4. Daily Precipitation	PRCP
5. Daily Snowfall	SNOW
6. Daily Occurrence of Weather	DYSW
7. Daily Average Wind Speed	AWND
8. Peak Gust Wind Speed and Direction	PKGS
9. Percent of Possible Sunshine	PSUN
10. Average Sky Coverage - Sunrise to Sunset	SCSS
11. Average Sky Coverage - Midnight to Midnight	SCMM
12. Daily Minimum Relative Humidity	MNRH
13. Daily Maximum Relative Humidity	MXRH

data base dealt with the formulation of the data base. In view of the massive data storage requirements (estimated at 3 gigabytes) and after much deliberation, a data base structure composed of three levels was recommended. Details of the recommended data base organization are as follows.

- *Raw climatic data*: The lowest level of the data base (referred to as the "low-level" data base) would consist of daily NCDC and CCC data cleansed of unnecessary codes and flags and stored "off-line" on long-term storage media. The data would be stored in the original system of units [U.S. customary for NCDC data and International System (SI) for CCC data] for individual weather stations, without direct linkage to individual pavement test sites. Statistical parameters would not be stored at this level.
- *Daily data, statistical parameters, and derived data*: The second level of the data base (referred to as the "middle-level" data base) would include daily data for individual weather stations and a virtual weather station corresponding to each test section, as well as the calculated statistical parameters and derived data for all of these stations. Data for the virtual station would be created using the following interpolation algorithm:

$$V_m = \frac{\sum_{i=1}^{k}\left(\frac{V_{mi}}{R_i^2}\right)}{\sum_{i=1}^{k}\left(\frac{1}{R_i^2}\right)}$$

where

V_{mi} = value of a data element on day m, station i;
R_i = distance of weather station i from the site;
V_m = calculated data element for Day m for the virtual weather station; and
k = number of weather stations for the site (up to five).

All data at this level would be stored in U.S. customary units for U.S. GPS sites and SI units for Canadian GPS sites. Also, the data would be stored off-line and would be associated with specific test sites for easy recovery.

- *Monthly summary data*: The final level of the data base (referred to as the "top-level" data base) would contain monthly summary data (calculated statistical parameters and derived data) from the individual weather stations as well as the virtual station. This portion of the climatic data base would be included in the National Pavement Performance Data Base (NPPDB).

As the storage scheme outlined above was being developed, consideration was given to processing the data and retaining only the final "virtual" values in NPPDB, with the thought that researchers desiring more detailed data could always go to NCDC and CCC for the original data. However, the members of the Environmental Data ETG believed strongly that this was not an appropriate course because a significant number of researchers were likely to want the raw data and should not have to duplicate SHRP's efforts to acquire the information. They also believed that it was important to have the real weather station data alongside the virtual data, so that researchers could evaluate the viability of the virtual data for themselves, in light of the individual weather station values. Also, it was suggested that the use of data from the closest weather station would be preferable to the use of virtual data in some instances. Thus, it was recommended that both measured and virtual data be stored in the NPPDB.

DATA COLLECTION AND QUALITY ASSURANCE

Upon approval of the plans, work began in earnest toward the physical development of the LTPP climatic data base. To make this process as efficient and cost-effective as possible, it was decided to subcontract the actual data collection and data base population effort to a company experienced with

this type of work. The major objectives of the subcontractor's work effort were

- To identify weather stations in the vicinity of pavement test sites included in the GPS study, and
- To acquire and process data from various weather stations for each of the above sites and to develop the climatic data base following specifications established by SHRP.

In essence, the end product of this effort was to be the development of the climatic data base for 777 GPS test sites.

To accomplish these objectives, three separate phases were undertaken. Under Phase I, the subcontractor was required to identify weather stations in the vicinity of the GPS pavement test sites using the criteria detailed earlier and approved by the Environmental Data ETG and to provide the list of weather stations to SHRP for review and approval. The Phase II work effort addressed the likely need for the identification of additional weather stations as a result of the addition of more pavement test sites to the GPS experiments or to replace, for one reason or another, those previously identified. Finally, under Phase III, the subcontractor was required to obtain and process the data for the final list of weather stations. It was initially estimated that 300 first-order and 2,000 cooperative weather stations would be used in the development of the climatic data base for the GPS experiments.

Selection of Weather Stations and Data Base Population

Formal development of the LTPP climatic data base began with the submission of the list of GPS test sites to the subcontractor. Using the latitude and longitude data provided for each test site on this list, the subcontractor identified the required five weather stations in the vicinity of the GPS test sites that satisfied the criteria discussed earlier.

After the initial weather station identification (and during the course of the necessary reselections), the four SHRP Regional Coordination Office (RCO) contractors were asked to assist in an evaluation of the degree to which the five weather stations identified for each GPS test site in their region were believed to represent conditions at the site. Each RCO was provided with the list of GPS test sites and the corresponding weather stations. In addition, guidelines were prepared to aid the RCO in this evaluation—for example, input from the state climatologists, weather-station-to-site distance, elevation difference, and terrain considerations.

The degree to which the selections were reviewed varied significantly from region to region according to whether the review was done directly by the RCO or whether the RCO relied on the state climatologists to perform the review. When the state climatologists were relied on, results were often delayed until long after the data collection had been completed; thus relatively few weather stations were rejected as being nonrepresentative of the weather conditions at the GPS site.

In the western region, however, an extensive in-house review was undertaken because of concerns regarding the rough terrain and long distances between weather stations and the GPS sites; this region represents the worst case in terms of the relationship between weather station and test sections. All GPS sites and their selected weather stations were located on large-scale topographical maps. All weather stations determined to be on opposite sides of a mountain ridge from the GPS site were deemed nonrepresentative. Similarly, weather stations at elevations significantly different from those at the GPS site were also deemed nonrepresentative.

All in all, the review of weather stations by the RCOs resulted in the rejection of more than 200 (of a total of more then 3,000). Also, a few additional GPS test sites were added to the original list. As a consequence, a follow-up effort was undertaken to identify new or alternative weather stations. Tables 2 through 4 give the final distribution of weather stations by distance and elevation difference to the site, categorized by type of weather station. The distribution of accepted weather stations per site is shown below (only 24 GPS sites are represented by fewer than three weather stations):

TABLE 2 First-Order Weather Station Distance and Elevation Difference Distribution

Elevation Difference (feet)	Distance (miles)							
	0 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50+	rejected	Grand total
0 - 100	66 (8.5%)	70 (9.0%)	45 (5.8%)	31 (4.0%)	29 (3.7%)	69 (8.9%)	0 (0.0%)	310 (39.9%)
100 - 200	8 (1.0%)	29 (3.7%)	27 (3.5%)	25 (3.2%)	13 (1.7%)	34 (4.4%)	0 (0.0%)	136 (17.5%)
200 - 300	5 (0.6%)	9 (1.2%)	7 (0.9%)	14 (1.8%)	11 (1.4%)	27 (3.5%)	0 (0.0%)	73 (9.4%)
300 - 400	5 (0.6%)	7 (0.9%)	5 (0.6%)	11 (1.4%)	3 (0.4%)	14 (1.8%)	0 (0.0%)	45 (5.8%)
400 - 500	3 (0.4%)	1 (0.1%)	2 (0.3%)	2 (0.3%)	5 (0.6%)	15 (1.9%)	0 (0.0%)	28 (3.6%)
500+	1 (0.1%)	4 (0.5%)	16 (2.1%)	10 (1.3%)	8 (1.0%)	41 (5.3%)	0 (0.0%)	80 (10.3%)
rejected	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	105 (13.5%)	105 (13.5%)
Grand total	88 (11.3%)	120 (15.4%)	102 (13.1%)	93 (12.0%)	69 (8.9%)	200 (25.7%)	105 (13.5%)	777 (100.0%)

TABLE 3 Active Cooperative Weather Station Distance and Elevation Difference Distribution

Elevation Difference (feet)	Distance (miles)							
	0 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50+	rejected	Grand total
0 - 100	329 (42.3%)	121 (15.6%)	18 (2.3%)	0 (0.0%)	0 (0.0%)	1 (0.1%)	0 (0.0%)	469 (60.4%)
100 - 200	70 (9.0%)	59 (7.6%)	12 (1.5%)	2 (0.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	143 (18.4%)
200 - 300	44 (5.7%)	17 (2.2%)	2 (0.3%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	63 (8.1%)
300 - 400	17 (2.2%)	13 (1.7%)	2 (0.3%)	1 (0.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	33 (4.3%)
400 - 500	8 (1.0%)	7 (0.9%)	1 (0.1%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	16 (2.1%)
500+	24 (3.1%)	22 (2.8%)	4 (0.5%)	0 (0.0%)0	0 (0.0%)	0 (0.0%)	0 (0.0%)	50 (6.4%)
rejected	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	3 (0.4%)	3 (0.4%)
Grand total	492 (63.3%)	239 (30.8%)	39 (5.0%)	3 (0.4%)	0 (0.0%)	1 (0.1%)	3 (0.4%)	777 (100.0%)

No. of Accepted Weather Stations	*No. of Sites*
5	634
4	86
3	33
2	18
1	6

On completion of the weather station selection process, the focus shifted to the retrieval of the climatic data for each selected weather station (see Table 1 for a list of the data elements extracted from the NCDC and CCC files). Processing of the raw data also yielded various monthly statistics and other "derived" data elements for inclusion in the climatic data base. These additional data elements and their derivations were discussed earlier.

Concurrent with the above effort, various activities were undertaken to finalize the structure of the climatic data base. Following the recommendations provided in the plans, the data base was defined as being made up of three levels: (a) raw climatic data (low level); (b) daily data, statistical parameters, and derived data (middle level); and (c) monthly summary data (high level). A description of each level was provided earlier. Next, the structure of each level and that of individual records within each level were finalized as were the formats for the various data elements. Finally, the computer code required to calculate the monthly statistics and other derived data was developed.

In all, 37 nine-track tapes containing over 3 gigabytes of climatic data were generated. The low-level data base contains 17 tapes with a total of 1.5 gigabytes of data. The middle-level data base also contains 17 tapes, with a total of 1.4 gigabytes of data. The top level of the data base contains three tapes with a total of 0.22 gigabyte of data. To ensure the quality of the data contained in these tapes, a series of checks was performed on them. These quality assurance checks and their outcome are discussed in the next section. After the successful completion of the quality checks, all three levels of the climatic data base were turned over to TRB, where

TABLE 4 Regular Cooperative Weather Station Distance and Elevation Difference Distribution

Elevation Difference (feet)	Distance (miles)							
	0 - 10	10 - 20	20 - 30	30 - 40	40 - 50	50+	rejected	Grand total
0 - 100	105 (4.5%)	423 (18.1%)	372 (16.0%)	78 (3.3%)	7 (0.3%)	3 (0.1%)	0 (0.0%)	988 (42.4%)
100 - 200	43 (1.8%)	160 (6.9%)	215 (9.2%)	37 (1.6%)	5 (0.2%)	0 (0.0%)	0 (0.0%)	460 (19.7%)
200 - 300	23 (1.0%)	104 (4.5%)	108 (4.6%)	25 (1.1%)	2 (0.1%)	2 (0.1%)	0 (0.0%)	264 (11.3%)
300 - 400	10 (0.4%)	50 (2.1%)	58 (2.5%)	19 (0.8%)	1 (0.0%)	0 (0.0%)	0 (0.0%)	138 (5.9%)
400 - 500	9 (0.4%)	34 (1.5%)	35 (1.5%)	19 (0.8%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	97 (4.2%)
500+	16 (0.7%)	106 (4.5%)	107 (4.6%)	27 (1.2%)	5 (0.2%)	0 (0.0%)	0 (0.0%)	261 (11.2%)
rejected	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	123 (5.3%)	123 (5.3%)
Grand total	206 (8.8%)	877 (37.6%)	895 (38.4%)	205 (8.8%)	20 (0.9%)	5 (0.2%)	123 (5.3%)	2331 (100.0%)

the NPPDB is now located. Both the low- and middle-level data bases are being stored off-line, whereas the top-level data base is stored in the NPPDB. Only data for the closest and virtual weather stations are currently in the NPPDB for each GPS test site because of storage limitations. An example of a portion of the top-level data is contained in Table 5.

Data Quality Assurance

To ensure the reliability of the data stored in the climatic data base, only data flagged as valid from NCDC and CCC were used in the development process. Additional quality control procedures included verification that all ordered and available data had been obtained and a thorough checking and review of the software used in the development of the data base. Furthermore, because there is a substantial amount of data in each level of the data base, quality assurance checks were performed separately on each level; for example, all tapes were checked for readability and completeness.

Readability checks included verifying that the data areas of the tapes contain only numeric characters. Any nonnumeric data found there indicated that either the tape was corrupted or the hardware had failed. Many of the checks described above were performed in a random fashion, with data observed throughout the entire data set. Where appropriate, virtual weather station data were compared with data from the nearest available weather station when they were in close proximity, to evaluate whether the calculated data were reasonably close to the measured data. Where both U.S. and Canadian weather stations were selected, samples of data were checked to determine whether unit conversions were performed appropriately. Also, for a small group of GPS sites and their selected weather stations, the entire set of data was entered on the data collection forms to verify that the forms and the computerized data collection process matched.

Finally, an additional set of NPPDB data checks is currently under way. These checks generally take several different forms. From the point of view of completeness of the data base, some data elements are checked simply to ensure their presence. Other data elements are checked against a range of values for that type of parameter to flag those that are out of the range of normal values. Still other data elements are checked against values contained in other data tables to maintain internal consistency. The climatic data base will not be released to the public until it has passed these quality assurance checks.

TABLE 5 Sample Top-Level Virtual Data for GPS Site 480001

Max Temperature					
(degrees F)	Jan	Feb	Mar	Apr	May
Average	68.06	69.57	70.00	79.06	87.90
Std Dev	8.326	7.946	8.858	6.601	5.889
Skewness	-0.617	-0.424	-1.390	-0.390	-0.541
Kurtosis	2.640	2.062	4.291	3.025	2.089
Frz/Thw	1	0	0	0	0
Miss Cnt	0	0	0	0	0
#>90	0	0	0	1	15
Min Temperature					
(degrees F)	Jan	Feb	Mar	Apr	May
Average	45.93	47.28	52.12	59.06	67.67
Std Dev	9.121	5.912	9.545	7.277	6.905
Skewness	0.569	0.185	0.089	-0.277	-0.448
Kurtosis	2.678	2.805	1.688	2.080	1.942
Frz Index	0	0	0	0	0
Miss Cnt	0	0	0	0	0
#<32	0	0	0	0	0
Precipitation					
(inches/100)	Jan	Feb	Mar	Apr	May
Average	4.26	12.32	8.55	10.76	11.80
Std Dev	8.644	24.310	21.110	34.510	38.120
Skewness	2.166	2.067	4.048	4.314	4.246
Kurtosis	6.393	6.080	20.160	21.700	21.340
Total	132	345	265	323	366134
#>0.5	0	3	1	1	3
#>0.01	12	11	15	11	11
Snowfall					
(inches/10)	Jan	Feb	Mar	Apr	May
Average	0	0	0	0	0
Std Dev	0	0	0	0	0
Skewness	-9999	-9999	-9999	-9999	-9999
Kurtosis	-9999	-9999	-9999	-9999	-9999
Total	0	0	0	0	0

FUTURE ACTIVITIES

Although significant effort has been spent on the development of SHRP's LTPP climatic data base, the work is far from complete. First, the climatic data currently available in the data base end somewhat before the writing of this paper. Because the majority of LTPP sections will be monitored for many years to come, future updates of the climatic data base will be required periodically. Also, despite the data base development effort to date, there are gaps in the data for a number of weather stations and some weather stations may not be representative of on-site weather conditions. To address both of these concerns, the feasibility of obtaining ground truth (actual or on-site) weather data through on-site weather stations needs to be investigated. Finally, it is important that an effort similar to the one discussed in this paper be undertaken to expand the LTPP climatic data base to include SPS tests sites. These three issues are discussed further.

Data Base Updates

The majority of SHRP sections, both GPS and SPS, will be monitored for many years. However, the climatic data currently stored in the LTPP data base includes information only through February 1991 for U.S. sites and through December 1989 for Canadian sites. Thus, future updates of the climatic data base will be required periodically. Current recommended plans call for these updates to be performed ever 2 years for each active GPS test site. As part of these updates, weather stations that have become inactive would be replaced by other weather stations of the same order (first order or cooperative) or higher. At the same time, a check would be made to verify whether any new stations have been established closer to the site than stations already included in the data base. In case such stations are identified, these stations will be added to the data base and new data for other existing weather stations

will not be collected. Historic data will be maintained in the data base even after a station has been dropped.

As the analysis of the LTPP data progresses, it may become necessary to collect and store additional data elements. Likewise, additional activities may be necessary in the future, depending on the result of the climatic data base verification study discussed below.

Collection of Ground Truth Data

Despite the effort that went into the development of the LTPP climatic data base, there are gaps in the data for a number of the weather stations selected. Furthermore, data obtained from the selected weather stations may not be representative of the actual, on-site weather conditions for a number of sites. To overcome these shortcomings, it is planned to obtain ground truth weather data to achieve the following:

- Evaluate the degree to which estimates derived from NCDC and CCC weather data are representative of actual, on-site weather conditions and
- Provide weather data for those sites for which no representative weather stations have been identified or to fill in gaps in the available data.

To analyze the uniformity in the weather pattern in the area of the test sites, the weather information from each of the selected weather stations will be compared statistically with virtual data derived from the others. Depending on the results of this analysis, the correlation between the weather stations and the location of the test site can be estimated. This analysis will consider only temperature and moisture, represented by mean temperature and total precipitation. It is further anticipated that the above analysis will be supplemented (and validated) by weather data obtained from weather stations installed at or near a limited number of GPS test sites.

On completion of the analysis of degree of representativeness, it is likely that on-site or ground truth weather stations will be required at a number of GPS test sites. As an absolute minimum, these weather stations would collect temperature, precipitation, and snowfall data. Other data elements such as wind speed and relative humidity would also be considered, but their inclusion would depend on a number of factors, including financial constraints.

Expansion to SPS Experiments

The availability of climatic data is as critical for SPS experiments as for the GPS experiments. The data elements given in Table 1 are also considered essential for each SPS site. In general, it is anticipated that a procedure similar to that described for the GPS sites will be followed to obtain climatic data for SPS sites. These data will be collected at a later date because the SPS experiments are very young. Also, in some cases, a more rigorous data collection effort may be required—that is, installation and operation of a weather station at the sites if a weather station is not located in the proximity of the test site. State climatologists will be requested to provide input regarding adjacent weather stations and the extent of their representativeness of the climate conditions at the test site before the data collection approach is selected.

Tentatively, the following guidelines have been established to assess the representativeness of the weather stations:

- Mean daily temperature (monthly) should be within 10 percent of that at the weather station.
- Daily precipitation (monthly) and daily snowfall (monthly) at the test site should be within 20 percent of that at the weather station.

If the weather station data do not meet these requirements, or if other reasons exist for not considering adjacent weather stations (poor quality of data, potential closure, etc.), a cooperative-type weather station will likely be established for these test sites. It is anticipated that since many of the test sites will be in remote locations, use will be made of commercially available weather stations capable of measuring the necessary climatic data. The use of these weather stations will also permit collection of solar radiation data at a few test sites.

SUMMARY AND CONCLUSIONS

This paper presents details on the development of the climatic data base for LTPP test sections. For the GPS test sites that have been in service, generally for a large number of years, past climatic data had to be collected from in-service weather stations in both the United States and Canada. Thus, the data base provides the best available estimate for the climatic data at each GPS test section. Efforts are currently under way to determine the reliability of the data base and to identify the need for ground truth weather stations at a small number of test sections.

The resulting data base is one of the most comprehensive climatic data bases developed; it contains climatic data applicable to each GPS test section from the date of construction of that section. The data base will be regularly updated as the LTPP program continues for another 15 years. A similar data base also will be developed for the SPS test sites. In addition, a more rigorous data collection effort (i.e., installation and operation of on-site weather station) will be implemented at a number of GPS and SPS sites to ensure that climatic data collected for these sites are truly representative.

ACKNOWLEDGMENTS

The work described in this paper was performed by PCS/Law Engineering under contract to the Strategic Highway Research Program, National Research Council. The authors gratefully acknowledge the cooperation and assistance of the SHRP staff; the SHRP Expert Task Group on Environmental Data, chaired by Richard Berg; the SHRP regional coordination contractors; and EarthInfo, Inc., the LTPP climatic data base subcontractor.

REFERENCES

1. *Development of SHRP's LTPP Climatic Database*. Draft Technical Report. Strategic Highway Research Program, National Research Council, Washington, D.C., 1992.
2. *Data Collection Guide for Long-Term Pavement Performance Studies*. Operational Guide SHRP-LTPP-OG-001. Strategic Highway Research Program, National Research Council, Washington, D.C., Jan. 1990.

Publication of this paper sponsored by Committee on Flexible Pavement Design.