U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

The Stream Segment and Stream Network Temperature Models:

A Self-Study Course

Version 2.0
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by

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Preface to the Second Edition

I am pleased to have had the opportunity to revise the first version of this set of course notes for the stream temperature models. In some ways, there have been many changes and in some ways the notes have stayed much the same. Generally, I was satisfied that the notes were both comprehensive and fairly easy to read. The exercises using SSTEMP have been upgraded to reflect advances in the software. Some additional material was added to better cover contemporary thremistors, and some, but not all, weak transitions and incomplete sentences have been corrected. A comprehensive index was added in an attempt to make these notes as useful as possible, and a few telling quotes have been added for spice. The goal has been to make this set of notes as stand-alone as possible and keep the file size down to something that is easily downloadable over the Internet today (March 2000).

Downsizing has generally been an advantage. The SSTEMP software has been rewritten for Windows, so all the old DOS-related material was eliminated and replaced simply with an Internet link to the new software and documentation. A set of Frequently Asked Question (FAQ) material also has been added as a supplement, again as an Internet link. Unfortunately, many of the most useful references originally supplied as photocopies had to be eliminated to make the download size easy enough to deal with. You will need to do some library legwork on your own if you want to follow up on some references that interest you.

Though SNTEMP is still in widespread use, more and more clients demand a Windows user interface. Our budget and the level of use do not permit the expenditure necessary to accomplish the software conversion at this time. Though several private consultants have expressed an interest in providing "value added" front or back end software, nothing substantive has been accomplished to date for SNTEMP.

I do not believe the days of a stand-up classroom training session for the temperature models are entirely over. Though much use is being made of the models in the arcane world of Total Maximum Daily Load (TMDL) analyses, there have not been many FERC hydropower relicensing projects recently. Until the immediate demand resurfaces, perhaps in conjunction with additional relicensing activity, these notes are what remain of the institutional knowledge invested in years of training in collaboration with Dr. Terry Waddle. I hope they prove valuable to you, either as a student or as an instructor. I say instructor because these notes may also serve as an instructor's lesson plan in the event that stand-up classes return. Time permitting, these notes will become a USGS Open File Report. I just hope that the material "lives" long enough to pass beyond the time I retire and is successfully "transferred" to the next in line, whoever that may be.

Have fun!

John Bartholow
5/2/2000

Could Lewis and Clark have made the first documented use of a (mental) temperature model?

"The junction of the Wisdom and Jefferson presented a familiar problem. Which river to follow? Lewis decided on the Jefferson, not because it was bigger (it carried less water than the Wisdom) but because it was warmer, 'from which I concluded that it had it's source at a greater distance in the mountains'." -- page 260 of Ambrose, S.E. 1996. Undaunted Courage. Simon & Schuster, NY. 521 pp.

TOPIC #1: THE GRAND VISION:
ORGANIZATION OF COURSE AND AGENDA

Time: 0.5 hours
Format: Participatory Introductions and Lecture/Reading
Objectives: (1) Introductions B why are individuals here?
(2) Understand the roadmap to see the big picture.

OBJECTIVES/DESIRED OUTCOME

(1) Review syllabus

(2) Each Topic will include material directed to be sufficient to:

- (a) accomplish objectives for that topic
- (b) provide a summary of important material
- (c) present Rules of Thumb based on experience (if appropriate)
- (d) suggest additional readings for more advanced learning
- (e) pose a few questions targeted at either recall, comprehension, synthesis, or evaluation, and
- (f) provide answers to those questions.

IF 312 SELF-STUDY COURSE SYLLABUS

INSTRUCTOR

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REQUIRED MATERIAL

Theurer, F.D., K.A. Voos, and W.J. Miller. 1984. Instream water temperature model. Instream Flow Information Paper 16. U.S. Fish Wildl. Serv. FWS/OBS-84/15. approx. 200 pp.

Bartholow, J.M. 1989. Stream temperature investigations: field and analytic methods. Instream Flow Information Paper No. 13. U.S. Fish Wildl. Serv. Biol. Rep. 89(17). 139 pp.

Access to the Internet is required, along with this notebook, selected readings marked in **bold** in each section, a calculator, and graph paper. Note that many figures and tables in this set of notes were taken or adapted from the above references.

PREREQUISITES

The IF312 course content requires no prerequisite. However, IF100 is highly recommended to see how stream temperature analysis fits into the framework of the Instream Flow Incremental Methodology. It is assumed that all students are familiar with the computer's DOS operating system.

PARTICIPATION AND EVALUATION POLICY

For proper completion of this course, students are expected to complete all of the required reading and hands-on exercises. The depth with which material is covered is left to the students' discretion, but all questions must be expressed and addressed either by the instructor or other students.

A final exam is required, with successful completion being an indicator of initial mastery of the material covered in the lessons. However, the exam will not be graded nor will academic credit be supplied.

GOAL

This course’s goal is to prepare the student, self-study or otherwise, to comprehend the basics of stream temperature modeling, to apply two specific models, and to evaluate the appropriateness of these models for real-world, biological problem solving.

OBJECTIVES OF CLASS

After completing this course, the dedicated student should be able to:

a. Understand the theoretical basis for model, including its assumptions and limitations.

b. Be fluent in the stream geometry, hydrology, and meteorology components of the model, and how combining these components creates a stream system description.

c. Understand how to enter data, run, and interpret results from the network and stream reach versions of model.

d. Be capable of calibrating the SNTEMP model given typical constraints, e.g., some data are missing.

e. Be capable of using the model to estimate unknown temperatures for the baseline condition and predict water temperatures under altered conditions.

f. Depending on the needs of individual students, he or she will be prepared to either:

   1. Conduct a “live” temperature investigation, including how to plan a cost-effective study, gather needed input data, assemble that data into appropriate formats, and display results in a communicative manner; or

   2. Be able to review a completed study performed by another individual or organization, to assure its quality by critically analyzing it’s modeling components and evaluating the achievement of study objectives.

To accomplish the goal and objectives for this class, the self-study student must be willing to independently read portions of complex technical material, work autonomously to comprehend examples provided, and test his or her knowledge by hands-on application to lab problems. Participating in a classroom setting will provide the additional dimension of collaborative, small-team problem solving, and offer a wider perspective of viewpoints and approaches through classroom discussions, and, occasionally, offer the opportunity for classroom presentations and/or field trips.

An additional goal of this class is for the material and its presentation to improve through time. Therefore, course evaluations will be routine.

ROADMAP

IF 312 is typically taught in a 36-hour week, Monday through Friday noon (Table 1.1), with supplemental homework assignments. In a self-study format, the material will, of consequence, be self-paced. However, it is urged that the student proceed in the specified sequence without skipping any lessons to best cover the material. The lectures (or self-study material) and exercises are timed and laid out approximately as follows:

Day 1 - Concepts and Terminology

Topic 1: The Grand Vision: Organization of Course and Agenda
Time: 0.5 hours
Format: Participatory Introductions and Lecture/Reading
Assignment: Review material
Objectives: (1) Introductions - why are individuals here?
(2) Understand the roadmap to see the big picture. Each Topic will include material planned to be sufficient to (a) cover a set of objectives, (b) provide a summary of important points, (c) present Rules of Thumb based on experience (if appropriate), (d) suggest additional readings, (e) pose a few questions targeted at either recall, comprehension, synthesis, or evaluation, and (f) provide answers to those questions.

Topic 2: Setting the Stage: Why Temperature Modeling?
Time: 1.5 hours
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand how modeling serves the “incremental” objective implicit in river system impact assessment and management.
(2) Appreciate the full range of biological importance of stream temperature.
(3) Cover common applications for which the model has been used.

Topic 3: Temperature Model Overview
Time: 0.5 hours
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand capabilities of the models.
(2) Introduce components within the models.
(3) Introduce important terminology.
(4) Cover basic assumptions and limitations.
(5) Appreciate the big picture of a temperature study.
(6) Understand the distinction between baseline and “what-if” applications.

Topic 4: Introduction to Stream Segment Temperature Model
Time: 0.5 hours
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: Prepare students to run SSTEMP and other models on computer.

Day 1 (Continued)

Topic 5: Introduction to Stream Segment Temperature Model - Exercise
Time: 3 hours (with interspersed break)
Format: Small group hands-on exercise/Discussion
Assignment: Assemble into small (3-5 person) groups and:
(1) Install SNTEMP program and data files.
(2) Skim SSTEMP documentation.
(3) Perform exercises given in workbook.
(4) Answer questions to exercises.
Objectives: (1) Familiarization with computer setup.
(2) Familiarization with component models.
(3) Recognize parameters and understand their definition.
(4) Get a feel for the sensitivity of model parameters.

Topic 6: Familiarity Doesn't Breed Contempt
Time: 1-2 hours
Format: Homework
Assignment: (1) Skim parts I and II of IP#16.
(2) Incorporate errata in IP#16.
(3) Look through remaining course material.
(4) Be prepared to ask questions tomorrow.
Objectives: Familiarization with location of information throughout the course material.

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Day 2 - The Data File Jungle

Topic 7: Questions from previous day
Time: 0.25 hours
Format: Discussion
Assignment: Be prepared to ask for clarification.
Objectives: Clarity, perspective, and understanding.

Topic 8: Lay of the Land: Spatial Description of Stream Network Layout
Time: 1 hour
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Introduce three major logical components of temperature model.
(2) Define all node types and cover their connectivity.

Day 2 (Continued)

Topic 9: How Time Flies: Temporal Description of Stream Temperature Model
Time: 1 hour
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand averaging periods and what that means for data collection.
(2) Understand theoretical constraints on model application.

Topic 10: Move It: Transport of Water and Heat within the Stream Temperature Model
Time: 1 hour
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand boundary conditions and forcing functions.
(2) Understand why SNTEMP is not a hydrology model.
(3) Understand the limitations of SNTEMP's maximum temperature calculation.

Topic 11: Cooking It: Meteorological Influences
Time: 1 hour
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Introduce meteorological data requirements.
(2) Understand the definition of meteorological variables.
(3) Understand representativeness considerations in meta data.

Topic 12: Mixing the Ingredients: Overall Data File Schema for SNTEMP
Time: 0.5 hours
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand the full range of input files.
(2) Understand general file building sequence.

Topic 13: Spatially Organized Data Files: Skeleton, Study, Stream Geometry, Shade, and Hydrology Node
Time: 1 hour
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand what data goes in which file.
(2) Understand specific file formats.
(3) Understand any defaults that are available.

Day 2 (Continued)

Topic 14: Temporally Organized Data Files: Time Period, Meteorology, Hydrology Data
Time: 1 hour
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand what data goes in which file.
(2) Understand specific file formats.
(3) Understand any defaults that are available.

Topic 15: Covering the Bases: Data File Understanding
Time: 1-2 hours
Format: Homework
Assignment: (1) Review listings of input data files.
(2) Cross-check data elements with file formats to know what every element means and where it goes.
(3) Be prepared to ask questions tomorrow.
Objectives: Familiarization with data, file content, and file formats.

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Day 3 - Making It Work

Topic 16: Questions from previous day
Time: 0.25 hours
Format: Discussion
Assignment: Be prepared to ask for clarification.
Objectives: Clarity, perspective, and understanding.

Topic 17: Missing Pieces: Options for Handling Missing Data
Time: 0.5 hours
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Learn what kind and how much missing data can be accommodated by model.
(2) Understand distinction between data filling and smoothing.
(3) Understand consequences of each option for filling or smoothing missing data.
(4) Know where and how to select appropriate options.

Day 3 (Continued)

Topic 18: Orchestrating SNTEMP: The Job Control File
Time: 1 hour
Format: Lecture/Reading
Assignment: Review notebook material
Objectives:
1. Understand the control features in the job control file, including titles, I/O switches, global calibration parameters.

Topic 19: Pushing the Buttons: Running SNTEMP
Time: 0.5 hours
Format: Lecture/Reading
Assignment: Review notebook material
Objectives:
1. Understand seven SNTEMP model sub-programs and their sequence.
2. Understand the job control update program (JBCNUD).
3. Understand which sub-programs produce which output files.
4. Understand how to run SNTEMP in a DOS environment.

Topic 20: Quality Assurance: Checking that SNTEMP is Getting the Input You Want
Time: 0.5 hours
Format: Lecture/Reading
Assignment: Review notebook material
Objectives:
1. Understand the spectrum of output files from SNTEMP.
2. Know where to look for echoes of the input data.
3. Learn how to spot (and fix) potential or actual errors.

Topic 21: Got the Runs?: Your First Run of SNTEMP
Time: 1.5 hours
Format: Hands-on Small Group Exercise/Discussion
Assignment: Using the same small groups of 3-5 people carry out Exercise #21.1
Objectives:
1. Know how to execute TDATCHK and understand any errors identified.
2. Know how to fix common errors in input data files.
3. Know how to execute SNTEMP and interpret its run-time, on-screen output.
4. Know how to examine SNTEMP’s output files for errors.
5. Know how to interpret SNTEMP’s goodness-of-fit statistics and understand their limitations.

Day 3 (Continued)

Topic 22: Global Warming?: How to approach SNTEMP calibration through sensitivity and error analysis
Time: 2 hours
Format: Hands-on Small Group Exercise/Discussion
Assignment: SNTEMP Exercises 22.1 through 22.5 (some optional)
Objectives:
(1) Understand and apply general formulation of global calibration functions.
(2) Evaluate results from multiple global calibration parameters.
(3) Understand how model errors can be correlated with errors or biases in input data using the TEXERR program.
(4) Understand how to choose a course of action in calibrating SNTEMP.

Topic 23: Digestion of Results
Time: 1-2 hours
Format: Homework
Assignment:
(1) Review today's activities and sort out as many questions as you can.
(2) Be prepared to ask questions tomorrow.
Objectives:
(1) Internalize elements of calibration, model evaluation through goodness-of-fit statistics, and utility programs.
(2) Be exposed to the most basic utility of SNTEMP.

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Day 4 - Practical Considerations

Topic 24: Questions from previous day
Time: 0.25 hours
Format: Discussion
Assignment: Be prepared to ask for clarification.
Objectives: Clarity, perspective, and understanding.

Topic 25: Field Data Collection: Practice and Problems
Time: 1.5 hours
Format: Lecture/Reading
Assignment: Review notebook material
Objectives:
(1) Know which data may be gathered from existing sources and which typically need to be gathered from the field.
(2) Know about various equipment for data collection, including thermographs and meteorological stations, photo-gray cards, clinometers, and dye studies.
(3) Understand key cost-efficient considerations in field data collection.
(4) Understand types of field problems commonly encountered and learn strategies for dealing with them.

Day 4 (Continued)

(5) Know how to estimate parameters for which data cannot be collected.

Topic 26: Lesser-Used SNTEMP Utilities
Time: 0.5 hours
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand capabilities of READRYAN and TSTATS.
(2) Understand distinction between time major and space major data display.
(3) Understand how spreadsheets can be useful in data file assembly and modification.

Topic 27: Other SNTEMP Utilities
Time: 2.5 hours
Format: Hands-on Small Group Exercises/Discussion
Assignment: SNTEMP Exercises 27.1 and 27.2 (with break as needed).
Objectives: Understand and apply TDELTAQ and TTMPFIT.

Topic 28: Muddy Streams
Time: 0.25 hours
Format: Student feedback
Assignment: Each student writes 1 to 3 questions about issues still puzzling them.
Objectives: For instructor to understand and be prepared to clarify continued confusion.
Topic 29: Meteorological Data: The Promise and the Reality
Time: Optional -- 1 hour
Format: Field Trip; Q&A
Assignment: Review notebook material
Objectives: (1) Understand kinds of data collected by established met stations.
(2) Understand biases inherent in meteorological data.

Day 5 - Review and Wrap-up

Topic 30: Turning the Muddy Stream Clear
Time: 1 hour
Format: Lecture/Reading/Discussion
Assignment: Review notebook material
Objectives: Clear up muddy issues.

Day 5 (Continued)

Topic 31: Model Review for the Modeler and the Reviewer
Time: 1 hour
Format: Class Discussion
Assignment: Review notebook material
Objectives:
  (1) List items students feel are important in model application review.
  (2) Synthesize items into coherent categories.
  (3) Understand importance of documenting data sources and assumptions.

Topic 32: Special Topics (depending on class interest)
Time: 1 hour (depending on time available)
Format: Lecture/Reading
Assignment: Review notebook material
Objectives:
  (1) Know about other water temperature models for special applications.
  (2) Know about the use of SNTEMP in integrated biological modeling.
  (3) Understand degree-day and MWAT calculations.
  (4) Understand possibilities for model “cheating” and its prevention.

Topic 33: Final Exam and Course Evaluation
Time: 1 hour
Format: Exam and discussion
Assignment: Complete exam and evaluation material
Objectives: Provide both student and instructor(s) feedback on accomplishment of class objectives.

RULES OF THUMB

Did you know that the Rule of Thumb was the first temperature model? Before thermometers were invented, brewers would dip a thumb into the mix to find the right temperature for adding yeast. Too cold, and the yeast wouldn't grow. Too hot, and the yeast would die. Thus, the Rule of Thumb. [Source: Hog's Head Beer Cellar Newsletter-10/97] I'll be giving you a few rules of thumb as we go through this material – little nuggets that may prove useful to you someday. I'll try to make them neither too hot nor too cold, but just right!

Table 1.1. IF 312 AGENDA

Time	Day 1 **Monday**	Day 2 **Tuesday**	Day 3 **Wednesday**	Day 4 **Thursday**	Day 5 **Friday**
8:00 am 8:30	*Registration* Organization	Questions Spatial Dimensions	Questions Missing Data	Questions Field Data Collection	Questions
9:00 am 9:30	Why Temperature Modeling?	Temporal Dimensions	Job Control File		Model Review
10:00 am 10:30	*Break*	*Break*	Running SNTEMP *Break*	SNTEMP Utilities *Break*	Special Topics *Break*
11:00 am	Model Overview	Heat Transport	Quality Assurance	Lab Exercises: Utilities	Final Exam Evaluation
12:00 pm	*Lunch*	*Lunch*	*Lunch*	*Lunch*	*End of Day*
1:00 pm	Introduction to Segment Models	Meteorology	Lab Exercise: Data and Model Checking	Exercises (Cont.)	
2:00 pm 2:30	Lab Exercises: SSTEMP *Break as Needed*	Data File Schema *Break*	*Break as Needed*	*Break as Needed*	
3:00 pm	SSTEMP cont.	Spatial Files	Lab Exercise: Calibration		
4:00 pm	SSTEMP cont.	Temporal Files		Field Trip	
5:00 pm	*End of Day*	*End of Day*	*End of Day*	*End of Day*	
	Homework	Homework	Homework	Group Dinner	

TOPIC #2: SETTING THE STAGE: WHY TEMPERATURE MODELING?

Time: 1.5 hours
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand how modeling serves the “incremental” objective implicit in river system impact assessment and management.
(2) Appreciate the full range of the biological importance of stream temperature.
(3) Cover common applications for which the model has been used.

Temperature and IFIM

One of the founding principles of the Instream Flow Incremental Methodology (known as IFIM) is that it is a process for impact assessment. Further, IFIM is built around a set of tools that may be used for impact “grading” i.e., measuring the relative merits and demerits of alternative proposals. This implies that the practitioner be able to say with some authority that Alternative A is better than Alternative B, and by how much. A common conceptualization of a water quality problem is to tabulate results of alternatives in “miles of suitable stream.” Those suitable miles/kilometers can then be evaluated for appropriate microhabitat characteristics, generally as one of several potential limiting factors. More complicated analyses may carefully factor in temporal availability in addition to geographic specificity, on a seasonal or finer time scale. In fact, water temperature criteria can conceptually cover any element of the ecological system, as described in the following section.

IFIM was developed specifically to allow quantification of the amount of potential habitat available for a fish species/life stage, in a given reach of stream, under different stream flow regimes. It is designed to:

1. help formulate instream flow recommendations,
2. assess the effects of altered stream flow regimes,
3. assess the effects of habitat improvement projects,
4. define and assess the effects of mitigation proposals,
5. assist in negotiating releases from existing storage projects,
6. assess the effects of proposed fish stocking programs, and
7. integrate fishery management concepts with water management activities.

IFIM is habitat based wherein potential usable habitat is simulated for unobserved flow or channel conditions. It is hydrologically driven, and usable habitat is simulated for two or more hydrologic time series. These simulations will include a baseline or reference time period (status quo), and one or more proposed alternative flow regimes *as if* the project were on line and operating over the same reference period. IFIM assumes that the evaluation species exhibit a documented preference/avoidance behavior to one or more physical habitat variables. These variables typically include velocity, depth, cover, substrate, and water quality, especially water temperature. The methodology assumes that fish (or other aquatic) populations respond to changes in environmental parameters that constitute usable habitat for the species.

IFIM divides the world into microhabitat and macrohabitat. Macrohabitat is defined as those characteristics of the environment affecting the distribution and abundance of species in a longitudinal sequence from stream headwaters downstream to the mouth. This is based on concepts of longitudinal succession developed by Shelford (1911) wherein species abundance and composition changes in response to gradational changes in environmental conditions. Typical macrohabitat variables include water chemistry, temperature, gradient, channel structure (e.g., rectangular, parabolic, triangular, trapezoidal), channel dimensions, channel patterns, discharge amount (sinuosity), and food source (allochthonous or autochthonous). Macrohabitat is typically modeled in one dimension, namely longitudinal. Though most people think immediately of PHABSIM and its important microhabitat variables of depth, velocity, and substrate/cover, macrohabitat is truly the larger and more dominant scale process. If macrohabitat is unacceptable for any reason, microhabitat is largely irrelevant. IFIM, of course, integrates both macrohabitat and microhabitat as shown in Figure 2.1. Though macrohabitat is technically defined to include gross channel morphology and flow regime, it is specifically the important role of water temperature as just one element of overall water quality that concerns us in this class.

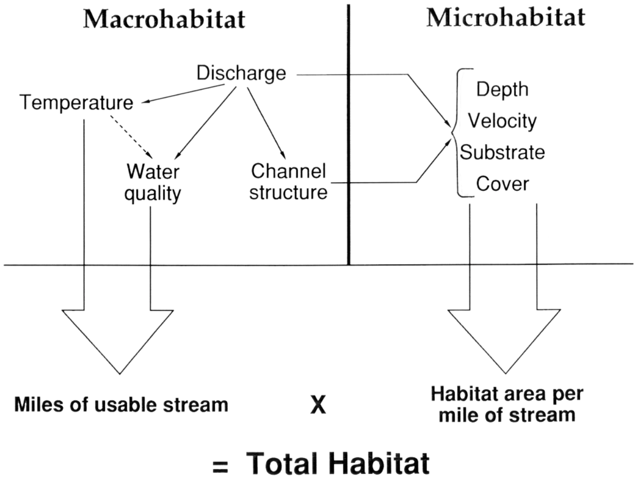


Figure 2.1. Integration of micro- and macrohabitat in IFIM.

In contrast to macrohabitat, microhabitat is defined as localized environmental conditions selected by a life stage or species to minimize interspecific competition, optimize energy budgets, maximize reproductive success, and/or avoid predation. This is based on concepts of ecological isolation and resource partitioning, corresponding to resting, feeding, spawning, or predator avoidance sites). When resting or feeding, optimization of energy budget is a primary driving force. For spawning or predator avoidance, maximum survival is the driving force. Typical microhabitat variables include depth, velocity, surface area, substrate, and cover type and distribution. Microhabitat is typically modeled in two (or sometimes three) dimensions.

IFIM is more often than not a search for one or more habitat bottlenecks -- one or more physical events resulting in the reduction in habitat availability for a life stage or life stages, that can ultimately be traced to a response at the adult population level. Thoroughly exploring potential habitat bottlenecks requires looking at total habitat, the spatial component of the realized niche defined by superposition of suitable macrohabitat conditions over the area of usable (realized) microhabitat (Figure 2.1).

If you think about it, fish populations are rarely directly related to the amount of habitat present at the time of measurement. The standing crop (biomass) and usable habitat values can be expected to be correlated only when measured at the time that the habitat is limiting and for the life stage that is habitat limited. Simultaneous measurement, however, is not sufficient. For a limitation to be operative, the population must be at "carrying capacity", that is not reduced or altered in number by some non-habitat factor such as fishing pressure, a pollution-caused fish kill, stocking, etc.

Temperature and Ecological Systems

There is far more known about the biological effects of water temperature on aquatic organisms than we could ever begin to cover in this class. Yet, as is the case with so much in the biological realm, though there is always more information available than one can ever use, there is rarely ever exactly what you want. Thus, the best we can do at this point is to cover the basic paradigm of how water temperatures influence aquatic systems and let you fill in the blanks, so to speak, for whatever system you are working on.

Thermal effects have been classified in several ways in the literature. A reasonable typology developed by Fry includes: (1) directive factors, (2) controlling factors, (3) lethal factors, (4) growth factors, and (5) synergistic factors. Coutant (1976) has yet a different scheme, factoring stress into the equation. Yet another classification might look like that shown in Table 2.1, in which the system effects of altered water temperature are divided into physiological, behavioral, temporal, and other water quality factors. In the following discussion, let’s interweave the schemes to the degree that we can.

Table 2.1. Biological effects of water temperature arrayed with increasing difficulty of acquiring definitive data as one goes down each column.

Physiology	**Behavior**	**Periodicity**	**Water Quality**
Survival	Habitat utilization	Incubation duration	Solubility of dissolved gasses
Growth rate	Activity	Onset of spawning	Deoxygenation rate
Embryonic development	Distribution	Onset of migration	Photosynthesis/ respiration
Susceptibility to parasites and diseases	Species interaction	Gonadal maturation	Synergistic toxicity

Lethal factors are usually considered life stage-by-life stage with criteria taking a form something like that shown in Figure 2.2 or 2.3. Acute lethal events typically occur at temperatures that are not markedly above from temperatures considered optimal and occur over periods of hours. Basically, the animal's homeostatic systems break down or are overwhelmed. Chronic lethal events lead to the destruction of the homeostatic systems in much the same way, just over longer periods of time on the scale of days or weeks. Typically, animals become more tolerant of temperatures, especially high temperatures, as they mature. Thus, eggs are more sensitive than are adults. Sublethal factors are thought to differ more among differing geographic races of fish than are relatively "fixed" lethal thresholds. In contrast, lethal limits are not generally statistically different between races.

Adaptation to any given temperature regime usually consists of a non-genetic and a genetic component. The genetic component is the evolutionarily significant basis for a species thermal tolerance; the non-genetic component remains a mystery, but does seem to influence sub-lethal performance of individual stocks. Until far more is learned, most people feel that it is inappropriate to develop stock-specific temperature standards (Oregon DEQ, 1995). It is this author's opinion that the human species has no business attempting to consciously accelerate evolution of other species by stressing their thermal tolerance limits. If we do, we will be inadvertently stressing our own limits whether we recognize it or not.

Directive factors can influence small-scale habitat use and associated behavioral activities (Figure 2.4); they can also influence the timing of fish life cycle activities (*phenology*, Figure 2.5): (1) trigger movement within the system being studied based on the thermal gradient, and (2) influence the initiation or termination of spawning behavior (Figure 2.6).

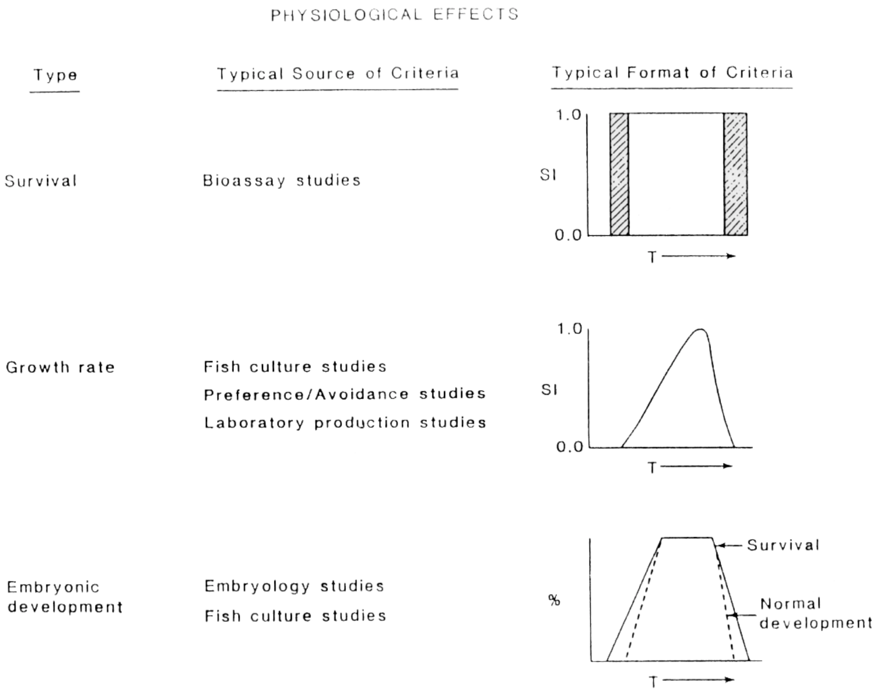


Figure 2.2. Physiological effects of water temperature and criteria that characterize them.

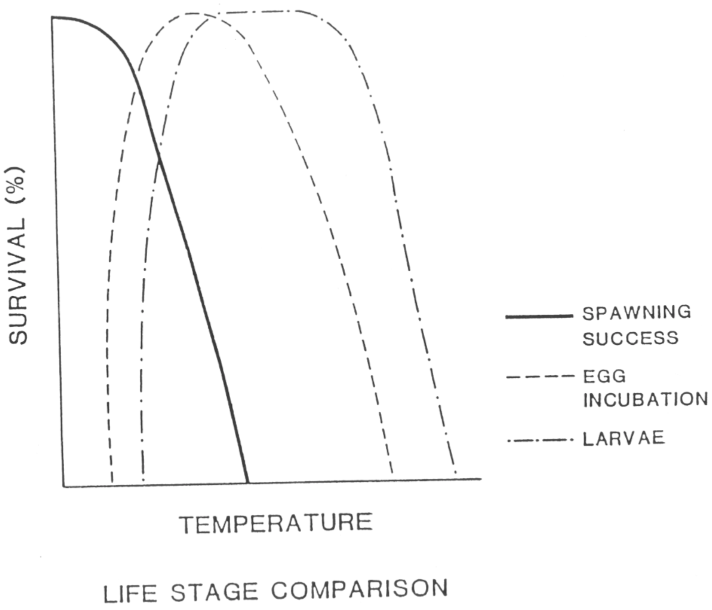


Figure 2.3. Characteristic differences in lethal responses to different life stages.

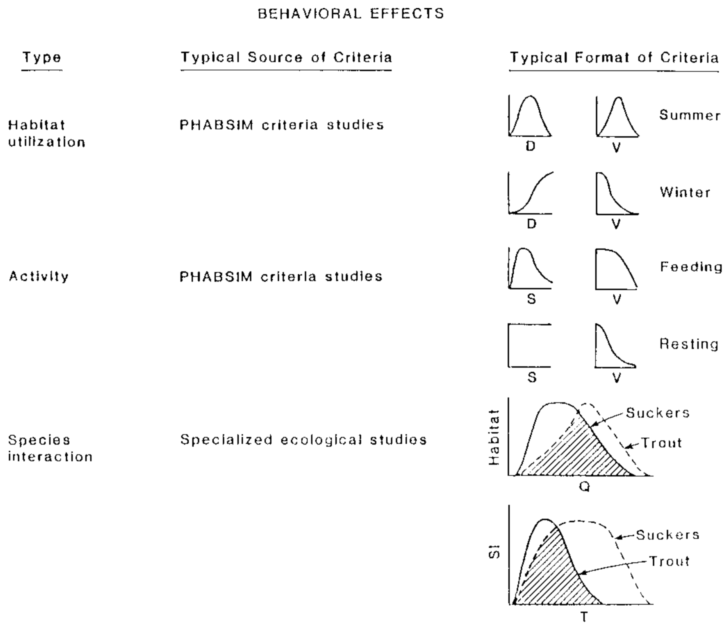


Figure 2.4. Effects of water temperature on behavior and criteria that characterize them.

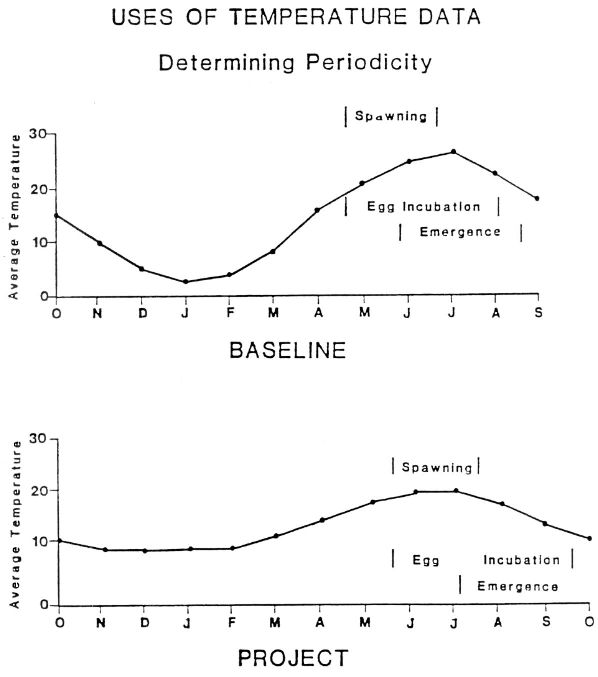
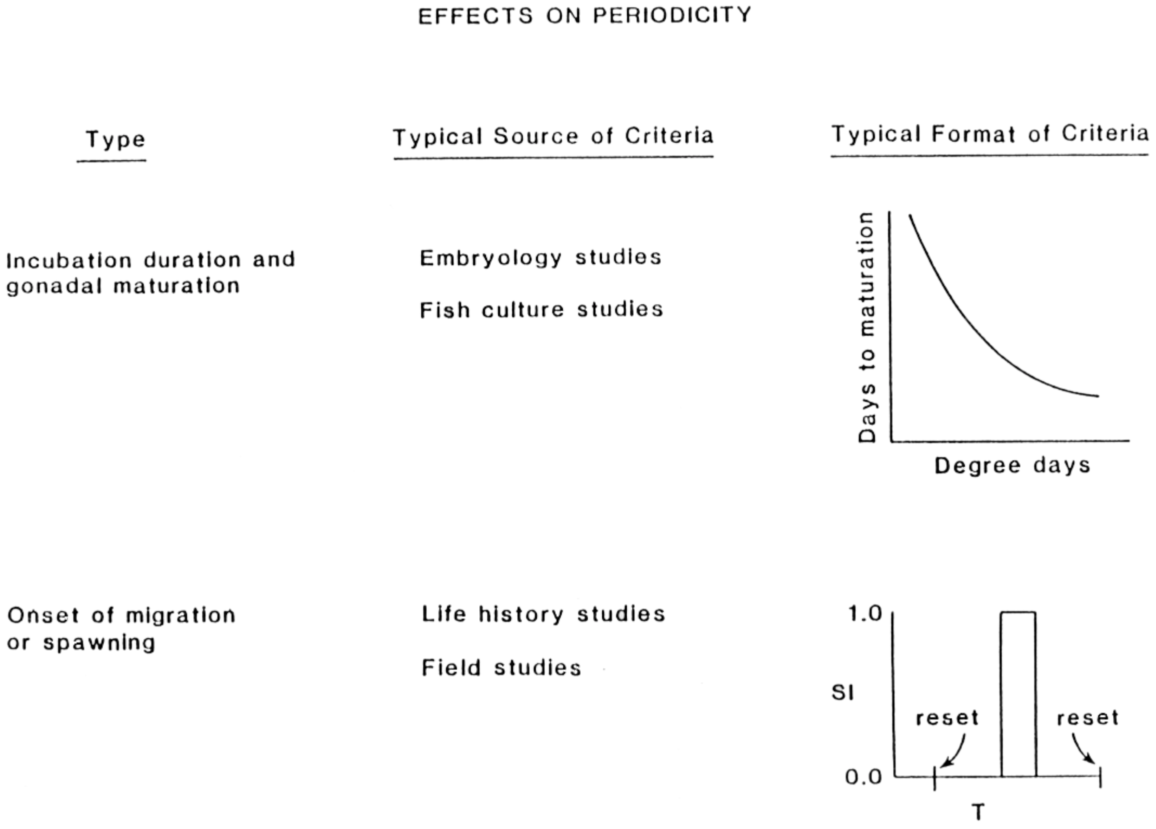


Figure 2.5. Changes in periodicity as a function of water temperature.



EFFECTS ON PERIODICITY

Type	Typical Source of Criteria	Typical Format of Criteria
Incubation duration and gonadal maturation	Embryology studies Fish culture studies	
Onset of migration or spawning	Life history studies Field studies	

Figure 2.6. Alternate ways to deal with temperature effects on periodicity.

Controlling factors refer to the governing (controlling) of process rates and act to determine the duration of the periods from incubation to hatch and from hatch to emergence. Thermal units called degree-days are useful to measure controlling factors. Both directive factors and governing factors confound the alternate categorization schemes between behavior and periodicity, but the schemes are far less important than the phenomena they attempt to categorize.

In general, for every 10°C increase in temperature, rates of biological activity double. Processes affected encompass small-scale reactions, such as enzymatic activity, up to and including whole organism responses, such as growth. Naturally, some processes more than double while some don't quite. Within a relatively narrow thermal "window" everything functions smoothly. However, continuing to raise the temperature eventually pits one metabolic process against another such that excretion, as an example, accelerates far beyond food consumption, effectively starving the individual fish. [Supposedly, if our body temperature was 86°F instead of 98.6°F, we could live to be about 200. Think of the metabolic consequences of that temperature difference.]

Fish *growth factors*, like controlling factors, are often considered a direct function of thermal unit experience assuming that the experience directly affects metabolic regulation. Growth is limited to a relatively narrow temperature range, usually having a thermal optimum with declining growth rate, or even growth inhibition, at temperatures on either side of the optimum. The relationship between growth and temperature, however, is complicated by intervening factors, principally food supply, that may either shift the optimum or influence the shape of the functional relationship. The growing field of bioenergetics is one way of addressing the effect of water temperature on fish growth. By breaking each metabolic function (e.g., respiration, excretion) down as a function of temperature, one can determine an organisms "scope for growth," the energy left over from consumption that can be devoted to either growth or reproductive development.

Synergistic factors simply mean that water temperature synergistically influences the biological response to other potential limiting factors. For example, water temperature directly effects how an organism reacts to waterborne toxics. Other physical processes may also be considered “synergistic,” such as the saturation of dissolved gasses, and photosynthesis (Figure 2.7).

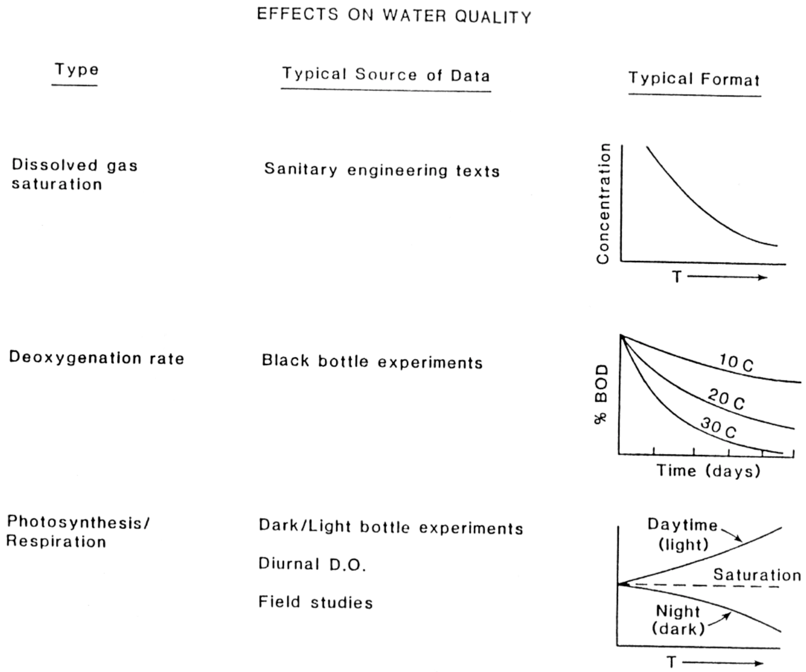


Figure 2.7. Effects of water temperature on water quality.

Temperature Model Applications

Application of temperature models has covered a wide spectrum. For our purposes here, I simply refer you to the paper by Bartholow (1995) in your readings that covers a decade of results with the temperature models, including a selected bibliography. Perhaps more importantly, let's take a moment and think more about the kinds of criteria that one might apply in judging whether one water management alternative is better than another. Table 2.2 covers the big picture in terms of criteria that might be developed. The *attributes* are those characteristics of water temperature (or most any hydrologic characteristic) that can be quantified. You could think of them as ways to describe the various waves of temperature an organism is exposed to. The *measures*, as the name implies, are "tangible" ways of quantifying the attributes. Also listed are *examples* of these metrics, and *integrators* that may be used to add a temporal dimension to the metrics, i.e., integrate it over time. I have stretched the point by including some spatial metrics and integrators that don't really follow suit, but use this as a mind-expansion device, not for any particular purpose. Also, you may be interested in a somewhat typology of metrics presented in Richter et al. (1997).

Table 2.2. Typology of Temperature Metrics

Attributes	Measures	Examples	Integrators
Magnitude	Min / Mean / Max Central tendency/diel variation	Point measures Median	LC50 (for a given thermal pattern) Maximum Weekly Average Temperature (MWAT) Degree days (w/ threshold) Time to 50% mortality Bioenergetics / Zero Net Growth
Frequency	# of occurrences in period	Days > threshold Recurrence interval	
Duration	# of consecutive occurrences / Persistence	Survival time	
Timing	Temporal window (averaging period) Initiation / cessation / "reset" Synchrony	Growing season (day, week, month, season) Onset of spawning / desmoltification / resorption Food availability	
Rate of change (of given magnitude and direction)	Diurnal cycle Seasonal pattern Annual trend	Thermal shock Constancy vs. "respite" Presence or absence of stimuli Acclimation (antecedent) "Global" warming	Bioenergetics?
Variation / distribution	Dispersion	10% exceedence	Coefficient of variation Skewness / kurtosis
Spatial extent	Composition / configuration Vertical / horizontal Reach level Catchment level Cluster of catchments Classification (Synchrony?)	Pool stratification / refugia Miles of stream suitable Fragmentation / connectivity / juxtaposition / phase difference Logged vs. unlogged / N-S vs. E-W	Spatial metrics of landscape mosaics Risk analysis - temporal and spatial Stratification

Not included: synergistic effects with other water quality parameters, measurement error considerations

RULES OF THUMB

Generally, criteria applied to gauge biological effects have fallen into two main categories. Historical IFIM analyses have advocated miles of stream of suitable macrohabitat. That is, microhabitat (PHABSIM) studies have produced square feet of usable habitat equivalents, but only for that portion of the stream with suitable macrohabitat. The second most often utilized criterion has dealt with reaching acute temperature thresholds. This could take the form of simply presence/absence of triggering the criterion, or be an index based on the number of days in a season the threshold was reached (i.e., violations) or something similar.

Many other criteria have been used, however. These include chronic thresholds (e.g., maximum weekly average temperature, or MWAT), various growth criteria (e.g., degree day accumulation during specified life history periods), and multiplying a temperature suitability index (0 to 1 scale) times the microhabitat values to calculate "total" habitat. To my knowledge, rate of change criteria, such as maximum-minimum daily temperature range or day-to-day variations, have not been applied, but probably should be.

It is my firm belief that we will see more and more criteria developed to characterize thermal *exposure* in ways that combine temperature with time. Degree-days (or degree-hours) above a specified threshold makes the most sense as a measure of stress to metabolic and enzymatic biological systems. These criteria should supplant acute thresholds since chronic conditions are largely responsible for species presence or absence. Also, rather than focusing on the "tolerable" effects of thermal pollution, biocriteria should establish an affirmative statement of desired ecological attributes (Adler, 1998). Unfortunately, this is easier said than done.

SUGGESTED READINGS FOR TOPIC 2

Adler, R.W. 1998. New TMDL litigation leaves many unanswered questions. Rivers. 6(1):269-274.

Armour, C. L. 1991. Guidance for evaluating and recommending temperature regimes to protect fish. U.S. Fish and Wildlife Service Biological Report 90(22). 13 pp.

Bartholow, J. M. 1991. A modeling assessment of the thermal regime for an urban sport fishery. Environmental Management 15(6):833-845.

Bartholow, J. 1995. The stream network temperature model (SNTEMP): A decade of results. Pages 57-60 *in* Ahuja, L., K. Rojas, and E. Seeley, editors. Workshop on Computer Applications in Water Management, Proceedings of the 1995 Workshop. Water Resources Research Institute, Fort Collins, Colorado. Information Series No. 79. 292 pp.

Coutant, C. 1976. Thermal effects on fish ecology. Pages 891-896 *in* Encyclopedia of Environmental Engineering, V2. W&G Baird, Ltd. Northern Ireland.

Havis, R. N., C. V. Alonso, J. G. King, and R. F. Thurow. 1993. A mathematical model of salmonid spawning habitat. Water Resources Bulletin 29(3):435-444.

Magnuson, J. J., L. B. Crowder, and P. A. Medvick. 1979. Temperature as an ecological resource. American Zoologist 19:331-343.

Richter, B. D., J.V. Baumgartner, R. Wigington, and D.P. Braun. 1997. How much water does a river need? Freshwater Biology 37:231-249.

Stalnaker, C., B. L. Lamb, J. Henriksen, K. Bovee, and J. Bartholow. 1995. The Instream Flow Incremental Methodology. A primer for IFIM. U.S. National Biological Service Biological Science Report 29. 44 pp. Available on the web at http://www.mesc.usgs.gov/pubs/online/ifim_primer/ifim_primer.htm

Theurer, F. D., K. A. Voos, and W. J. Miller. 1984. Applications. Part I in Instream water temperature model. Instream Flow Information Paper 16. U.S. Fish and Wildlife Service. FWS/OBS-84/15. approx. 200 pp.

Theurer, F. D., I. Lines, and T. Nelson. 1985. Interaction between riparian vegetation, water temperature, and salmonid habitat in the Tucannon River. Water Resources Bulletin. American Water Resources Association 21:53-64.

Voos, K. A., W. S. Lifton, and D. A. Gilbert. 1987. Simulation of the Stanislaus Project: Performance of the U.S. Fish and Wildlife Service instream temperature model on a complex system. Pages 746-755 *in* B. W. Clowes, editor. Waterpower 87: Proceedings of the international conference on hydrology. Portland, Oreg. 19-21 August 1987.

REVIEW QUESTIONS FOR TOPIC 2

1. One important item in scoping a temperature study is deciding on the study area. How might current or potential water temperatures influence your decision on study area delineation from a biological perspective, not just a physical perspective?

2. Explain how the distinction between microhabitat and macrohabitat can get muddied.

ANSWERS FOR TOPIC 2

1. The tricky part is trying to second-guess the biological responses to temperature changes. If new stream segments become accessible due to beneficial temperature changes, should they be included? If migrational responses change, should the study area change accordingly? Rule of thumb – be generous in study area because things always change.

2. In general, microhabitat is thought of as taking place roughly on the scale of a fish, i.e., several square meters. In contrast, macrohabitat is generally thought of along the river's longitudinal axis, usually on a scale greater than 7-10 times the channel width. But what happens if fish are found using thermal refugia, say at the mouths of cold-water tributaries, during certain times of the year? These "microhabitat" features may be governed by water temperature, but be spatially determined by channel form and flow. Thus, scale alone is insufficient to distinguish macro- from micro-habitat.

TOPIC #3: TEMPERATURE MODEL AND MODELING OVERVIEW

Time: 1 hour
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand capabilities of the models.
(2) Introduce model components.
(3) Introduce important terminology.
(4) Cover basic assumptions and limitations.
(5) Appreciate the big picture of a temperature study.
(6) Understand the distinction between baseline and “what-if” applications.

Capabilities

SNTEMP was developed by Dr. Fred Theurer, U.S. Soil Conservation Service in the early 1980's. Development took three to four years and consumed approximately $200-300K. The work was largely an extension of previous modeling efforts by Grenney (SSAM IV), Johnson, and Tennessee Valley Authority. Quigley's work on riparian shade formed the basis for the shading routines.

The temperature models have been applied in connection with many different kinds of impact analysis. More often than not, there is some sort of reservoir involved. Thus, either discharge timing, release temperature, release volume, or some combination of all three, may be analyzed for their effect on downstream water temperatures. If not a reservoir, irrigation diversions, the effect of timber management on riparian shading, and channel change have made up the bulk of other applications. The two applications described in IP#16 reflect all of the above in one form or another. Thermal loading, as from power plants or waste discharge facilities, makes up the final set of possibilities.

Technically, SNTEMP is unique as far as I know in the range of capabilities offered. Not only does the model deal with “standard” applications, it also facilitates dealing with missing data and provides goodness-of-fit statistics. In total, SNTEMP’s six modules are:

1. Heat flux - predicts the energy balance between the water and its surrounding environment. By convention, heat flux is defined as the arithmetic sum of the following components, which form the core of SNTEMP (see Figure 3.1):

NET HEAT FLUX = + SOLAR RADIATION
+ ATMOSPHERIC RADIATION
+ VEGETATIVE (AND TOPOGRAPHIC) RADIATION
+ EVAPORATION
+ CONVECTION
+ CONDUCTION
+ FRICTION
- WATER'S BACK RADIATION

2. Heat transport - predicts average mean daily and diurnal water temperatures as a function of stream distance.

3. Solar model - predicts solar radiation penetrating the water as a function of latitude, time of year, and meteorological conditions.

4. Shade model - predicts interception of solar radiation due to topography and riparian vegetation.

5. Meteorological model - predicts changes in air temperature, relative humidity, and atmospheric pressure as a function of watershed elevation.

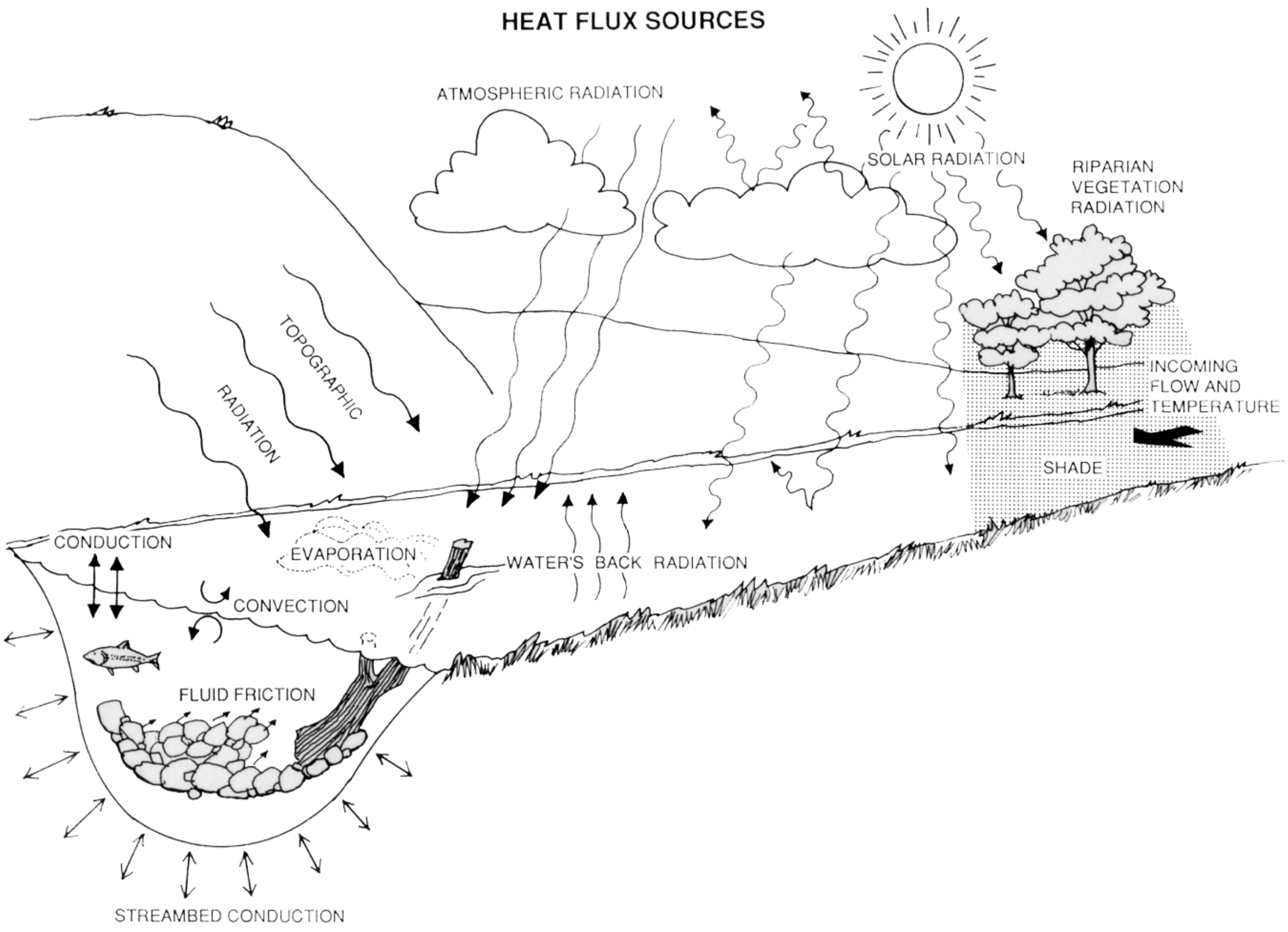
6. Regression model - aids in filling missing water temperature data or smoothing that data.

SNTEMP is also unique in the variety of solution techniques offered. The original version was developed for HP-34C and HP41C hand calculators. Though these versions are no longer supported, a simplified version for PC use, SSTEMP, is available. Though originally developed solely for classroom use, SSTEMP has proven valuable for simplified systems and initial problem scoping. The so-called network model is written in extremely portable Fortran 77 and is thus easily available for PC, Unix, or mainframe use. All of the models and utilities are integrated for relatively seamless application. There are a variety of utilities available to ease the pain of quality assurance/quality control, and gaming. In addition, there is a stand-alone shade model that has been applied, in modified form, by many other modelers using different stream temperature models.

Components and Data Requirements

Conceptually, SNTEMP may be divided into three broad functional areas: stream geometry, hydrology, and meteorology. Each has its own set of concepts to grasp, largely through an appreciation of the data required to “run” them, the sensitivity of that data, and the

Figure 3.1. Heat flux components modeled in SNTEMP and SSTEMP.



relationship of that data to other model components. SNTEMP has been set up to use data that are relatively easy to gather in one form or another.

Stream Geometry data consists of:

1. The network layout, largely from maps supplemented by field observations.
2. Site elevations, generally from topographic maps.
3. Stream widths, generally from field measurements.
4. Manning's n (or time of travel), generally from field or simulation studies.
5. Shade estimates, generally from field measurements.

Meteorologic data consists of:

1. Solar radiation, generally from published data or assumed to be predictable by SNTEMP.
2. Air temperature, generally from weather service or field measurements.
3. Relative humidity (ditto).
4. Wind speed (ditto).
5. Cloud cover, occasionally from weather service observations, but less readily available than it once was.

Hydrologic data consists of:

1. Stream discharge, generally from USGS gages (or WATSTORE), or CD-ROM (e.g., Hydrodata).
2. Water temperatures, generally from gaging or field measurements. Headwater temperatures may also be synthesized by SNTEMP.

Assumptions and Limitations

There are several assumptions that apply to SNTEMP. These assumptions in turn dictate the limitations in terms of model applications.

First, SNTEMP is a **steady state** model. It assumes that the conditions being simulated involve only steady flow BB no hydropeaking can be simulated unless the flows are essentially constant for the entire **averaging period**. The minimum averaging period is one day. Similarly, the boundary conditions of SNTEMP are assumed homogeneous and constant. This has implications for the maximum size of the network simulated for a single averaging period. We will cover this item in more detail in a later discussion.

Second, SNTEMP assumes homogeneous and instantaneous mixing wherever two sources of water are combined. There is no lateral or vertical temperature distribution (dispersion or diffusion), represented in the models.

Third, SNTEMP itself is meant solely for stream temperature predictions. It will not handle stratified reservoirs, though river-run reservoirs with equilibrium releases may be simulated.

Fourth, SNTEMP is NOT a hydrology model. It can not be relied on to distribute flows in an ungaged network. This is often an additional, non-temperature model task.

Fifth, SNTEMP may not be reliable in very cold conditions, i.e., simulating water temperatures less than about 4°C. It is not meant for ice or the like.

Finally, SNTEMP and SSTEMP have been tested only in the northern hemisphere.

A Temperature Study: The Big IFIM Picture

Most of you have been introduced to the essential components of a plan of study in previous IFIM work. However, experience has shown that even excellent guidance has not resulted in excellent study plans. So bear with me as I repeat some elements that are especially important for macrohabitat considerations. First, better pre-study involvement between all members of the "team" needs to be stressed. That is, planners, field data collectors, modelers, statisticians, decision makers, regulators, resource interests, developmental interests, and reviewers all need ACTIVE involvement to:

(1) Identify the management problem (goals and objectives) -- what is it that you are really doing? Does this study deal with water rights or flow reservations? Is it to assess project impacts, evaluate mitigation, or approve permits? If it is an impact analysis problem, what is the appropriate baseline period with which to compare impacts? Are we at the feasibility or operational stage in the planning process? Is this a single project or a network of projects? Who are the players?; who has the lead? How "important" is this project?; is there much resistance to a study of this type?

(2) Identify the appropriate species/life stages of concern. Is this a game, sport, or commercial fishery problem? Is it a sensitive or indicator species problem? Is it an endangered species problem? Is it a "guild" of species or a planned introduction? Are we talking about a naturally sustaining population, supplemental stocking, or a put-and-take fishery? Do we have adequate life history information for periodicity and macrohabitat (temperature and water quality) preferences?

(3) Identify the relevant variables to be measured/predicted. Is the minimum, mean, or maximum temperature, or some combination of values the issue? Is a daily, weekly, or monthly averaging period appropriate? What is the spatial extent of your study area?

(4) Identify the appropriate criteria to employ. Are we talking about growth, mortality, trigger temperatures, temperature change rates, "minimum" flows, total available fish habitat, population size, dollars, or commercial or recreational fishing effect? Do not proceed until criteria have been formulated and agreed to by all parties.

(5) Identify the quantitative measures for decision-making (miles of suitable stream, temperature-conditioned microhabitat, hatching times, etc.). How concerned must we be about accuracy and/or precision? Do different players need different information to do their job? Is there a favored method that has been used by local agencies?

(6) How much time, money, and labor can (or should) be devoted to the problem and solution analysis? What is the time frame for decisions to be made? Can field studies be scheduled? What are realistic management options? Are there opportunities for partnering with other agencies or the public to reduce financial resource requirements?

Knowing the management problem(s) can give you some clues about possible solutions. Though it would be incorrect to prejudge solutions at this stage of the game, it is appropriate to continually keep your eyes open to possibilities, particularly as you are in the field. Knowing the species life history is important because all too often mechanical or "cookbook" application of techniques ignores common sense about limiting factors or other requirements that should not be overlooked. Coming to grips with the temporal and spatial issues leads to important considerations in choosing models or other analysis techniques, and getting the jump on how model output is to be used in the decision process. *A priori* agreement on the criteria (with maybe only a bit of wiggle room) and measures for decision making leads to a surety of purpose and a commitment to negotiate on scientific findings rather than on speculation. Making sure your objectives are as tight as possible will reduce the scope of work by eliminating extraneous data collection. Finally, as always, the practical issues must be factored in to be realistic and efficient.

In one sense, study planning ensures that the necessary data of sufficient quality are gathered to go into a structured decision process. Often, a large part of that decision process is front-ended by models. Models are useful in identifying first order effects where an alteration results in direct impact to target organisms. Usually, however, first order effects are reasonably self-evident because they so often result in an acute response where the impact to target organism is immediate and demonstrable (i.e., belly-up fish). Examples of first order macrohabitat effects are: (1) thermal effluent raises water temperature to lethal levels; (2) organic municipal wastes deplete dissolved oxygen levels to lethal levels; (3) agricultural runoff, chiefly nitrogen and phosphorous, causes eutrophication of streams and lakes; (4) agricultural or silvicultural practices result in excess sedimentation, choking spawning gravels; (5) hard rock mining leads to acid drainage and carries toxic quantities of lead, arsenic, zinc, cadmium, or copper, and (6) cold hypolimnetic releases from reservoirs with low dissolved oxygen severely reduce suitable habitat for downstream warmwater communities.

Models help in two ways. First, they assist in identifying the inputs and outputs of the first order effects, which may help one get, a handle on useful management options. However, models really shine in facilitating the identification and description of second order problems resulting in indirect or chronic effects, where the impacts to target organisms occur in less obvious ways or extend over longer time horizons. Examples of second order effects include: (1) Reduced flow results in less water volume, lower surface area, and reduced velocity. Cumulatively, this results in elevating water temperature, concentrating the existing BOD load, and reducing reaeration. Biologically, dissolved oxygen is depleted below lethal levels causing mortality. (2) Reduced streamflow results in dewatering of riffles that eliminates habitat for aquatic invertebrates. The result is a depauperate stream that otherwise could support fish in the remaining pools. (3) Hydropeaking results in large and rapid flow fluctuations. Indirectly, the location of suitable habitat changes from place to place as the flow changes. The result is that organisms that cannot readily move or do so only with a high energetic cost are lost from system. (4) The thermal regime alters the balance of competitive advantage between cold and warmwater fishes. Fisheries eventually become endangered, affecting the public's perception of, and economic support of, possible solutions. The result is significant political pressure being brought to bear, which changes the balance of power from present consumptive uses to altered restorative goals. Which of course leads to yet other consequences . . . As you can see, at some point the models no longer help.

Study Design Summary

In general, there are 10 steps to a typical temperature analysis. One wonders if there is really such a thing as a "typical" analysis. This is just one of many explanations.

1. Refine system goals and objectives.

2. Determine the “potential” impact area by professional opinion, consultation, or scoping level analysis.

3. Determine “all” species (fish, macroinvertebrates, etc.) and life stages that use “potential” impact area: when, where, what activities.

4. Select target species based on pre-selected criteria.

5. Refine impact area given more specific objectives.

6. Select study sites.

7. Gather temperature criteria for target species, usually from literature.

8. Assemble and calibrate the model to measured field data.

9. Model temperature response under all alternative operation scenarios.

10. Integrate macrohabitat with microhabitat and interpret results.

11. Implement mitigation plan.

12. Monitor the system response.

13. Revise models if necessary.

RULES OF THUMB

"Perfection of means and confusion of goals seem to characterize our age." – Albert Einstein

Temperature modeling, rather like any kind of impact assessment, bears a strong comparison to the ideas of Buddhist reincarnation. If you don't have pretty specific objectives, more or less universally agreed to by most stakeholders, you will repeat the work over and over until you do (or you die). The model itself, being physically based, will in all likelihood work well if you have accepted its assumptions and limitations, and clearly know your objectives.

SUGGESTED READINGS FOR TOPIC 3

Theurer, F. D., K. A. Voos, and W. J. Miller. 1984. Physical processes and math models. Part II *in* Instream water temperature model. Instream Flow Information Paper 16. U.S. Fish and Wildlife Service. FWS/OBS-84/15. approx. 200 pp.

REVIEW QUESTIONS FOR TOPIC 3

Why is it that everyone ignores our advice for making sure your objectives are clear before doing anything else?

ANSWERS FOR TOPIC 3

1. Because we are all quite good at ignoring our own good advice.

2. Because objectives evolve through time as the players learn more about the system, its physical limits, its biological responses, and the costs and consequences of single-purpose management actions.

3. Because we still are so ignorant about temperature requirements of biological systems.

4. And probably a host of other reasons.

There is something to the *ready, fire, aim* scheme after all. It's just that it would be so better stated *ready, aim, fire, measure deviation, adjust aim, fire, measure deviation, etc.*

TOPIC #4: INTRODUCTION TO STREAM SEGMENT TEMPERATURE MODELS

Time:	0.5 hours
Format:	Lecture/Reading
Assignment:	Review notebook material
Objectives:	Prepare students to run SSTEMP and other models on computer.

Scoping Level Temperature Model – SSTEMP

Streams today, especially in the western United States, are subject to a variety of forms of degradation. Often one subtle change is stream temperature. Most problems causing stream temperature effects probably fall into four categories: (1) impoundment construction and operation; (2) removal of instream water through diversions or groundwater pumping; (3) riparian vegetation destruction due to grazing, farming practices, timber management, or flooding; and (4) stream channel alteration due to grazing, channelization or mining. Resulting stream temperature changes can have a profound influence on the quantity and quality of aquatic life supported by the stream. The astute manager will consider stream temperature as one variable in their impact or mitigation analysis.

It has long been difficult to predict how alternative management actions influence stream temperatures. But now readily available microcomputer programs make such calculations relatively painless. These programs help in comprehending the factors that control stream temperatures, understanding the sensitivity of those factors, and accurately estimating the effects of changing those factors through planned management actions. One of these programs, the Stream Segment Temperature Model, is described in this topic. A sequence of steps is outlined to introduce the program, help in estimating or measuring model variables, and grasp the significance of the program's output. In Topic 5, an example problem and solution are presented to reinforce the material. Though simplistic, the example adequately represents a common real-world situation.

The Stream Segment Temperature Model differs from the Network model in four distinct ways. First, the Segment model, as the name implies, deals only with a single stream segment, not an entire dendritic network with tributaries, withdrawals, and returns. Second, only one time period may be simulated for any given "run". Though it is comparatively easy to change the time and/or space conditions in SSTEMP, it is a manual process subject to human bookkeeping errors and tedium. Third, the segment model can use English units in addition to metric. Finally, SSTEMP can perform an automated first-order sensitivity analysis.

SSTEMP does three things. First, given the time of year, location of the study area on the earth's surface, and some meteorological data, it computes the solar radiation likely available at the earth's surface. Next, that radiation is reduced by topographic shading and riparian vegetation. Finally, the radiation is combined with all other sources of heat entering or leaving the water to compute downstream water temperatures given upstream conditions.

RULES OF THUMB

> "For an artist to marry his model is as fatal as for a *gourmet* to marry his cook: the one gets no sittings, and the other gets no dinners." - Oscar Wilde

Why pick one model (SNTEMP or SSTEMP) over the other? If the number of time periods multiplied by the number of geographic reaches exceeds 30, it is far better to use SNTEMP than SSTEMP. This becomes especially true as it is so often the case that analyses need to be redone, given a small change in an operations scenario, or a minor data error found late in the process. SNTEMP requires more of an up-front burden in terms of program setup, but will quickly pay for itself in the ability to respond quickly later in the life of the project.

SUGGESTED READINGS FOR TOPIC 4

Readings follow lab exercises in Topic 5.

TOPIC #5: INTRODUCTION TO STREAM SEGMENT TEMPERATURE MODEL - EXERCISE

Time:	3 hours (with interspersed break)
Format:	Small group hands-on exercise/Discussion
Assignment:	Assemble into small (3-5 person) groups and: (1) Install SNTEMP program and data files per Exercise 1. (2) Skim SSTEMP user's guides at the beginning of Exercise 2. (3) Perform exercises 2-5 as time permits. (4) Answer questions to exercises.
Objectives:	(1) Familiarization with computer setup. (2) Familiarization with SSTEMP model. (3) Recognize parameters and understand their definition. (4) Get a feel for the sensitivity of model parameters.

NOTE: SNTEMP is strictly a DOS-based program. All instructions in this manual and on the diskette assume DOS operation. In addition, most of SNTEMP's output files are in 132-column format. Extra hoops may needed to get these files to print properly on laser or other printers. Often, utilities are available to put the printer in landscape mode and print in a font suitable to the task. Alternately, setting the printer manually will typically suffice.

EXERCISE 5.1: INSTALLING SNTEMP & SSTEMP ON YOUR COMPUTER

Point your browser to http://www.mesc.usgs.gov/rsm/rsm_download.html#TEMP and download the four files *sntemp.exe, ssunzip.exe, sntutils.exe*, and *sntdata.exe*. It would be wise to save them to a disk that has quite a lot of space as these are all files that have been compressed and will take up much more room their full form, approximately 12 MB. Save them in a directory called SNTEMP for the moment. Each of these four programs may have been compressed with a different utility, so don't be surprised if they act somewhat different when you deal with them subsequently.

Run the program *sntemp.exe* by double clicking on it or typing its name if in a DOS window. You should get a series of seven other executables (.EXE), two batch files (.BAT), one document (.DOC) and an errata file (.TXT). Depending on how you execute this program, you may need to close any DOS window it opens to decompress the files. The errata file is for Information Paper 16. Your copy may already have an errata page inserted in it. The DOC file contains additional read-me type information you may choose to read. SNTEMP.BAT is the batch file used to run SNTEMP and the IF312.BAT file is one we have used in classroom settings to standardize how everyone deals with sample data sets. Look over all the non-executable files briefly to see how they work and what they are doing. We will actually uses these later in the week.

Run the program *sntutils.exe*. This will provide another 20 or so utilities (.EXE) and their documentation files (.DOC). We will cover the utilities in later Topics. Do the same with *sntdata.exe*. This gives you a complete set of sample data and corresponding output files, along with some bad (.BAD) data files you will use for testing in a later exercise.

The big step is next. Run the program *ssunzip.exe*. Unless you have a good reason otherwise, allow it to unzip its contents into the *Windows/Temp* directory. Navigate to the *Temp* directory and run the file *Setup.exe*. Depending on your system configuration, you may be asked if you want to keep newer system files. You also may need to reboot your computer and once again run the *Setup* program. I'm just going to trust that you can do all of this. I will also trust that you can set paths, create directories, and so forth in DOS mode, all of which you will need to do to become a proficient user of SNTEMP.

You may now delete the four files you originally downloaded -- *sntemp.exe, ssunzip.exe, sntutils.exe*, and *sntdata.exe* to save room on your computer.

Congratulations. That's all for installing!

EXERCISE 5.2: USER’S GUIDE TO THE STREAM SEGMENT TEMPERATURE MODEL

Defining the Problem

No set of computer programs can ever tell you what you are trying to do; you have got to define that for yourself. You must decide before proceeding what the problem is and give some thought to what might be done about it. For example, do you know or suspect that grazing may have resulted in a particular stream exceeding critical thermal thresholds for a fish species of interest? Could it be that a proposed timber sale will encroach on a stream and you want to know how temperatures will be affected? Do you need to decide how much water can be diverted from a stream and still keep maximum temperatures below some threshold? Do you even have a handle on what those thresholds are and how close you may be to them. What management actions may be available to you to influence stream temperatures? Can you help control the bank slope, prevent overgrazing, or control streamflow? These things must be known. Given that these generalities have been defined, you should reduce the scope somewhat by putting temporal and spatial bounds on the problem. Narrowing the scope to a particular time of year and a specific geographic area will help immensely. Luckily, these decisions are usually not difficult. Doing so will also help you get started on temperature modeling, because these models assume that you are looking at a stream with a defined length during a certain season.

Once you have defined your objectives, the SSTEMP program may be a good place to begin your scoping exercise. The remainder of this section covers how to run and interpret the results from SSTEMP. In what follows, it is assumed that all stream data are characterized by average conditions. It is also assumed that water in the system is instantaneously and thoroughly mixed at all times. Thus there is no lateral temperature distribution across the stream channel, nor is there any vertical gradient in pools. Finally, as previously mentioned, SSTEMP is only valid for Northern Hemisphere applications.

Take a moment to look through the documentation for SSTEMP. It will really pay off to understand what you are doing and perhaps prevent you from making some assumptions that mistakenly get carried along from application to application. When you are satisfied that you understand the basics, proceed to the following example.

A Worked Example

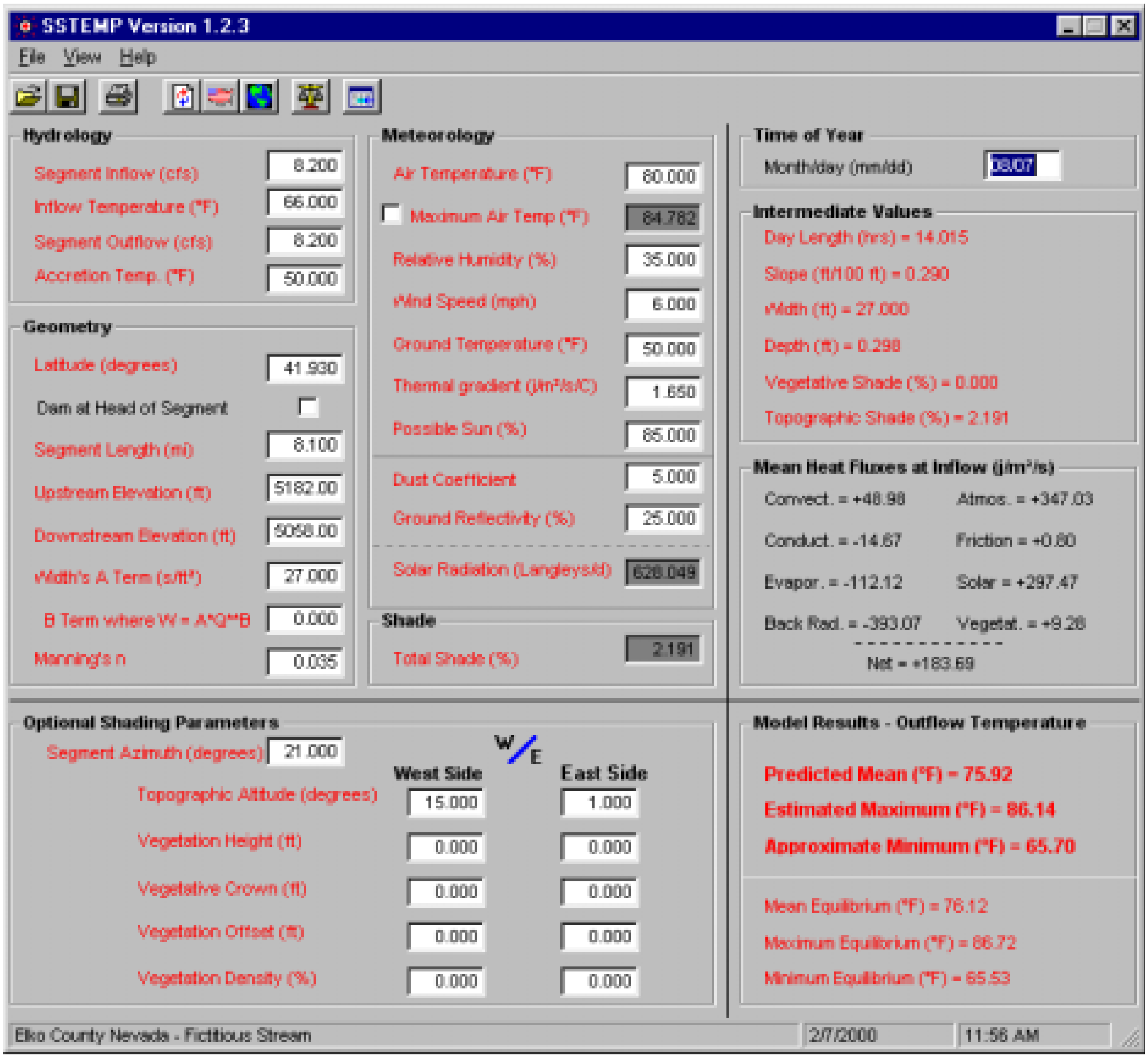
You have been asked to evaluate the potential thermal benefit of restoring an 8.1-mile section of overgrazed stream in northeastern Nevada that is thought to have high water temperature problems. You have little time and no money to devote to a detailed assessment. But a brief site visit is always in order, taking with you a topographic map, measuring tape, clinometer, and calibrated thermometer. After this, and two phone calls, one to USGS, and one to the local weather service, you are ready to begin.

Your site visit reveals a high gradient stream flowing out of some hills into a broad, open grassland. The stream has been severely degraded, supporting virtually no riparian vegetation. At the foot of the hills, you take a water temperature measurement between 10 a.m. and 2 p.m. to get an estimate of the mean daily temperature. At several locations, you measure the stream width and take clinometer measurements of the topography. Taking a few photographs can aid your memory when you get back to the office.

Your phone calls have told you a lot. The weather service had a local observer near your site where they kept air temperature records from 1949 to 1986. They look up the statistics for you. August is the hottest month, with a mean monthly maximum air temperature of 94°F, standard deviation of 3°F. The mean monthly minimum air temperature was 54°F, standard deviation also 3°F. The average of these, plus two standard deviations to account for the 95% extreme condition, is 80°F. The mean annual temperature is 50°F, a good starting point for the ground temperature.

Luckily, USGS has had some gages in the area since 1918. If the stream were ungaged, that means more work for you. But if there are nearby records, you can get an idea of when flows are low and their approximate magnitude. In this case, USGS can estimate the minimum August flow to be about 8.2 cfs. This is not the lowest *daily* flow on record for August, but the minimum *monthly* flow, probably more representative of persistent low flow conditions. You decide to concentrate on the first two weeks in August.

If you are not a fisheries biologist, you must make one more phone call. That call, or a look in a book, will reveal that trout in the area will not live in a stream where maximum daily temperatures exceed 77°F. Using what you have learned and some of the data from the maps in the reference section, you are ready to fire up SSTEMP. Let's look at the screen after you have entered some of your data:



Hydrology

Segment Inflow (cfs) 8.200
Inflow Temperature (°F) 66.000
Segment Outflow (cfs) 8.200
Accretion Temp. (°F) 50.000

Geometry

Latitude (degrees) 41.930
Dam at Head of Segment ☐
Segment Length (mi) 8.100
Upstream Elevation (ft) 5182.00
Downstream Elevation (ft) 5058.00
Width's A Term (s/ft²) 27.000
B Term where W = A*Q**B 0.000
Manning's n 0.035

Meteorology

Air Temperature (°F) 80.000
☐ Maximum Air Temp (°F) 84.782
Relative Humidity (%) 35.000
Wind Speed (mph) 6.000
Ground Temperature (°F) 50.000
Thermal gradient (J/m²/s/C) 1.650
Possible Sun (%) 85.000
Dust Coefficient 5.000
Ground Reflectivity (%) 25.000
Solar Radiation (Langleys/d) 626.049

Shade

Total Shade (%) 2.191

Time of Year

Month/day (mm/dd) 08/07

Intermediate Values

Day Length (hrs) = 14.015
Slope (ft/100 ft) = 0.290
Width (ft) = 27.000
Depth (ft) = 0.298
Vegetative Shade (%) = 0.000
Topographic Shade (%) = 2.191

Mean Heat Fluxes at Inflow (j/m²/s)

Convect. = +48.98
Atmos. = +347.03
Conduct. = -14.67
Friction = +0.80
Evapor. = -112.12
Solar = +297.47
Back Rad. = -393.07
Vegetat. = +9.28
Net = +183.69

Optional Shading Parameters

Segment Azimuth (degrees) 21.000

	West Side	East Side
Topographic Altitude (degrees)	15.000	1.000
Vegetation Height (ft)	0.000	0.000
Vegetative Crown (ft)	0.000	0.000
Vegetation Offset (ft)	0.000	0.000
Vegetation Density (%)	0.000	0.000

Model Results - Outflow Temperature

Predicted Mean (°F) = 75.92
Estimated Maximum (°F) = 86.14
Approximate Minimum (°F) = 65.70

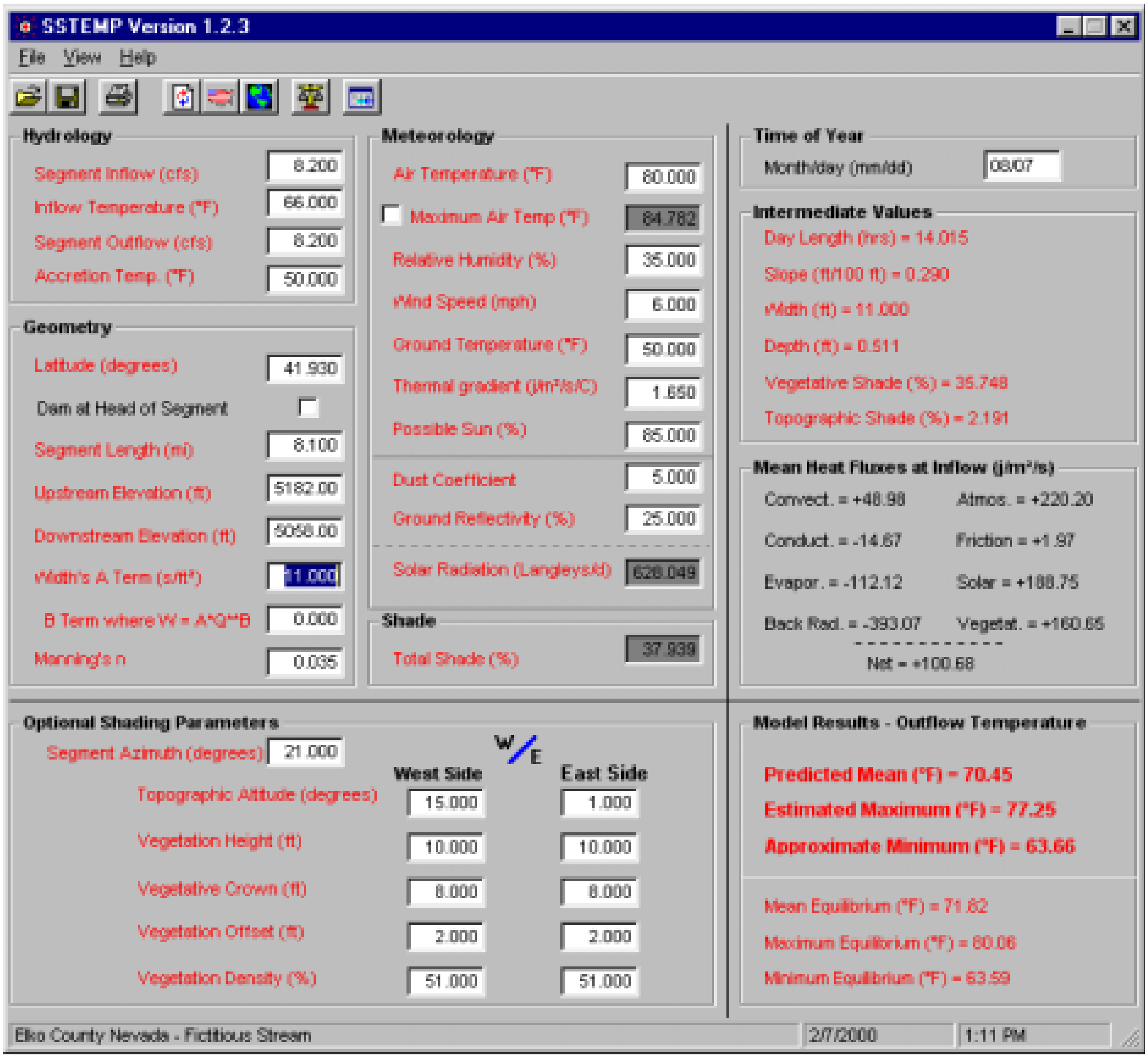
Mean Equilibrium (°F) = 76.12
Maximum Equilibrium (°F) = 86.72
Minimum Equilibrium (°F) = 65.53

Elko County Nevada - Fictitious Stream
2/7/2000
11:56 AM

The SSTEMP output tells you that there are about 626 Langleys per day entering the unshaded water, and that daylight lasts about 14 hours. The total shade only amounts to about 2%. Note that under these conditions, daily maximum water temperatures exceed 86 F, though just barely, totally unacceptable in the downstream reaches of this stream.

Next you must estimate the potential improvements resulting from a revised grazing plan. Calls to your hydrologist result in estimates of a new stream width – 11 feet. Your own experience tells you that you can expect about 60% of the stream bank to be vegetated with willows or alders that screen about 85% of the sunlight (.6*.85 = .51, or 51% total density) for a "virgin" stream in this area. You also estimate their height, etc., and that the increased streambank vegetation and meanders will somewhat retard the flow of water. The resulting shade for the restored condition is:

Thus, the shade has been increased from 2% to 38%. What about temperature for the restored condition? It looks like this:



Hydrology

Segment Inflow (cfs) 8.200
Inflow Temperature (°F) 66.000
Segment Outflow (cfs) 8.200
Accretion Temp. (°F) 50.000

Geometry

Latitude (degrees) 41.930
Dam at Head of Segment ☐
Segment Length (mi) 8.100
Upstream Elevation (ft) 5182.00
Downstream Elevation (ft) 5058.00
Width's A Term (s/ft²) 11.000
B Term where W = A*Q**B 0.000
Manning's n 0.035

Meteorology

Air Temperature (°F) 80.000
☐ Maximum Air Temp (°F) 84.782
Relative Humidity (%) 35.000
Wind Speed (mph) 6.000
Ground Temperature (°F) 50.000
Thermal gradient (J/m²/s/C) 1.650
Possible Sun (%) 65.000
Dust Coefficient 5.000
Ground Reflectivity (%) 25.000
Solar Radiation (Langleys/d) 628.049

Shade

Total Shade (%) 37.939

Time of Year

Month/day (mm/dd) 08/07

Intermediate Values

Day Length (hrs) = 14.015
Slope (ft/100 ft) = 0.290
Width (ft) = 11.000
Depth (ft) = 0.511
Vegetative Shade (%) = 35.748
Topographic Shade (%) = 2.191

Mean Heat Fluxes at Inflow (j/m²/s)

Convect. = +48.98　Atmos. = +220.20
Conduct. = -14.67　Friction = +1.97
Evapor. = -112.12　Solar = +188.75
Back Rad. = -393.07　Vegetat. = +160.65
Net = +100.68

Optional Shading Parameters

Segment Azimuth (degrees) 21.000

W/E	West Side	East Side
Topographic Altitude (degrees)	15.000	1.000
Vegetation Height (ft)	10.000	10.000
Vegetative Crown (ft)	8.000	8.000
Vegetation Offset (ft)	2.000	2.000
Vegetation Density (%)	51.000	51.000

Model Results - Outflow Temperature

Predicted Mean (°F) = 70.45
Estimated Maximum (°F) = 77.25
Approximate Minimum (°F) = 63.66

Mean Equilibrium (°F) = 71.82
Maximum Equilibrium (°F) = 80.06
Minimum Equilibrium (°F) = 63.59

Elko County Nevada - Fictitious Stream　2/7/2000　1:11 PM

The result of decreasing the width and increasing the shade and Manning's n has been to lower the maximum daily temperature to just below the 77°F threshold. In fact, it is so close that given an uncertainty of roughly 2°F for this kind of scoping analysis, you must expect that not all of the stream will be thermally protected all of the time. Removing uncertainty, if necessary, will cost you in terms of more detailed data collection. But you can be assured that the temperature conditions can be greatly improved.

That's how it works.

EXERCISE 5.3

1. You have been put in charge of developing a “trophy” trout fishery just below Flaming Desire dam outside of Grand Junction, Colorado. Using data from Grand Junction’s Local Climatological Data (LCD) and from “Input Data for Solar Systems,” (both of which follow) develop a temperature model for the following stream in the month of July:

a. Monthly discharge	60.38 cms
b. Discharge temperature	9.29°C
c. Lateral flow	0.0208 cms/km
d. Reach length	43.4 km
e. Elevation at dam	1672.0 m
f. Elevation downstream	1631.0 m
g. Stream width at 60.38 cms	60.96 m
h. Width exponent	0.18
i. Reach shading	30%

2. Determine the sensitivity of your model to changes in each of the variables you consider relevant. In particular, vary the discharge from 30 to 110 cms. Plot mean water temperature versus discharge. (If you get ambitious, you might try the MATRIX option in SSTEMP.) Does it make any difference that there is a dam at the upstream point? Why or why not? Make a table showing how changes in input values effect temperature (maximum and average). Are the sensitivities you have found “situation dependent?”

3. These trophy trout have been shown to achieve optimum growth when the average daily maximum temperatures range from 11 to 18°C. What extreme conditions might arise in this area to push the water temperature out of the desired range? What management actions could be taken to keep temperatures in the optimum range under these extreme conditions? Under “average” conditions, how far downstream can the fishery be maintained?

4. Suppose you had a simple two-branched stream network. Can you think how you could use this microcomputer model to handle it?

5. Which items must be varied in tandem to maintain an accurate representation of your system?

6. What are the limitations and weaknesses of this version of the temperature model?

Local Climatological Data page 1

Local Climatological Data

Annual Summary With Comparative Data

1982

GRAND JUNCTION, COLORADO

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

Narrative Climatological Summary

Located in a large mountain valley, the junction of the Colorado and Gunnison rivers, on the west slope of the Rockies, Grand Junction has a climate marked by the wide seasonal range usual to interior localities at this latitude. Thanks, however, to the protective topography of the vicinity, sudden and severe weather changes are very infrequent. Elevation of the valley floor ranges from 4,400 to 4,800 feet above sea level, with mountains on all sides at distances of from 10 to 60 miles, reaching heights of 9,000 to over 12,000 feet.

This mountain valley location, with attendant "valley breezes" provides protection from spring and fall frosts, resulting in a growing season averaging 191 days in the city of Grand Junction. This value varies considerably in the outlying districts, is about the same in the upper valley around Palisade, and 3 to 4 weeks shorter near the river west of Grand Junction, where the "valley breeze" is less effective. Farming areas located on mesas also enjoy longer frost-free seasons than adjacent lower lying ground where cool air tends to collect at night; this effect is more noticeable in the west, or lower portion of the valley. The growing season is sufficiently long to permit growth commercially of almost all fruits except citrus varieties. Summer grazing of cattle and sheep on nearby mountain ranges is extensive; foundation herds are wintered in the valley and there is some winter feeding of fat cattle and sheep.

The interior, continental location, ringed by mountains on all sides, results in quite low precipitation in all seasons. Consequently, agriculture is dependent on irrigation, for which an adequate supply of water has been available from mountain snows and rains. Summer rains occur chiefly as scattered light showers from thunderstorms which develop over nearby mountains. Winter snows are fairly frequent, but mostly light and quickly melt off. Even the infrequent snows of from 4 to 8 inches, which are heavy for this locality, seldom remain on the ground for prolonged periods. Blizzard conditions in the valley are extremely rare.

Temperatures at Grand Junction have ranged from 105° to -23°, but readings of 100° or higher are infrequent, and about one-third of the winters have no readings below zero. Summer days with maximum temperatures in the middle and low 90's and minima in the low 60's are common. Relative humidity is very low during the summer, with values close to such other dry localities as the southern parts of New Mexico and Arizona. Spells of cold winter weather are sometimes prolonged due to cold air becoming trapped in the valley. Winds are usually very light during the coldest weather. Changes in winter are generally gradual, and abrupt changes are much less frequent than in eastern Colorado. "Cold Waves" are rare. Sunny days predominate in all seasons.

Flying weather conditions are generally favorable for operation of light airplanes, with visibilities of 20 miles or more and ceilings of 5,000 feet or higher prevailing approximately 95 percent of the time. Gusty surface winds are rather frequent in the spring and early summer. The prevailing wind is from the east-southeast due to the "valley breeze" effects, but the strongest winds are usually from the south and southwest, and are associated with thunderstorms or with pre-frontal weather.

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / NATIONAL ENVIRONMENTAL SATELLITE, DATA, AND INFORMATION SERVICE / NATIONAL CLIMATIC DATA CENTER ASHEVILLE, N.C.

LCD page 2

Meteorological Data For The Current Year

Station: GRAND JUNCTION, COLORADO # 23066 WALKER FIELD Standard time used: MOUNTAIN Latitude: 39° 07' N Longitude: 108° 32' W Elevation (ground): 4843 feet Year: 1982

Month	Temperature °F							Degree days Base 65 °F		Precipitation in inches						Relative humidity, pct.				Wind						Percent of possible sunshine	Average sky cover, tenths, sunrise to sunset	Number of days											Average station pressure mb
	Averages			Extremes						Water equivalent			Snow, Ice pellets			Hour 05	Hour 11	Hour 17	Hour 23	Resultant		Average speed m.p.h.	Fastest mile					Sunrise to sunset			Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperature °F				
																(Local time)																				Maximum		Minimum		
	Daily maximum	Daily minimum	Monthly	Highest	Date	Lowest	Date	Heating	Cooling	Total	Greatest in 24 hrs.	Date	Total	Greatest in 24 hrs.	Date					Direction	Speed m.p.h.		Speed m.p.h.	Direction	Date			Clear	Partly cloudy	Cloudy					(b) 90° and above	32° and below	32° and below	0° and below	Elev 4839 feet m.s.l.
JAN	35.4	16.5	26.0	48	19	-3	8	1203	0	0.29	0.16	1	3.4	1.8	1	78	61	66	76	05	1.4	7.6	35	18	21	57	6.2	8	7	16	6	1	0	4	0	10	30	1	852.0
FEB	44.8	24.6	34.7	62	28	-3	7	841	0	0.41	0.18	16	4.0	2.3	3-4	75	57	50	75	08	1.8	6.8	17	14	20	64	6.5	6	9	13	5	1	0	2	0	5	20	3	854.7
MAR	57.1	34.9	46.0	68	18	25	20	581	0	0.79	0.22	26-27	0.8	0.8	3	68	45	37	62	15	1.2	9.7	35	18	18	65	6.6	6	10	15	11	0	1	0	0	0	11	0	848.3
APR	65.1	37.5	51.3	77	30	22	8	405	0	0.09	0.06	23	T	T	1	51	26	21	40	30	0.9	11.2	39	21	1	83	5.0	14	5	11	2	0	0	0	0	0	8	0	850.7
MAY	74.7	48.0	61.4	87	26	33	6	136	33	0.75	0.25	2-3	0.0	0.0		57	34	29	46	17	1.5	10.1	32	21	9	78	6.7	7	8	16	7	0	5	0	0	0	0	0	848.6
JUN	87.2	57.2	72.2	102	28	43	6	6	229	0.21	0.14	30	0.0	0.0		41	21	17	32	16	2.8	11.6	41	35	25	88	4.4	16	5	9	5	0	2	0	11	0	0	0	849.6
JUL	93.5	64.4	79.0	101	21	46	6	2	443	0.35	0.19	8-9	0.0	0.0		50	27	19	35	15	3.2	9.3	29	32	5	93	4.1	14	13	4	4	0	6	0	23	0	0	0	853.0
AUG	90.4	65.9	78.2	100	1	60	26	0	415	0.94	0.42	1-2	0.0	0.0		62	39	34	52	13	4.1	8.7	28	07	12	78	6.4	4	16	11	8	0	9	0	19	0	0	0	855.4
SEPT	78.6	56.3	67.5	94	3	45	14	61	144	2.81	† 1.02	10-11	0.0	0.0		66	49	42	59	13	5.2	9.4	35	27	28	64	7.0	5	6	19	12	0	6	0	4	0	0	0	852.4
OCT	63.5	40.3	51.9	76	4	29	11	397	0	0.83	0.58	26-27	T	T	27	66	40	34	54	07	1.7	8.1	29	30	7	75	5.7	10	8	13	5	0	1	0	0	0	1	0	855.1
NOV	50.2	32.2	41.2	63	7	23	16	704	0	0.48	0.22	10-11	T	T	29	77	56	52	73	10	1.7	7.3	39	31	19	58	5.6	9	7	14	5	0	0	1	0	0	16	0	852.7
DEC	41.8	24.2	33.0	53	10	9	30	983	0	0.27	0.16	23-24	1.9	1.4	23-24	73	59	57	75	07	2.1	6.8	32	27	23	67	6.0	11	6	14	3	1	0	0	0	4	29	0	853.4
YEAR	65.2	41.8	53.5	102	JUN 28	-3	FEB 7	5319	1264	8.22	1.02	SEP 10-11	10.1	2.3	FEB 3-4	64	43	38	57	12	1.8	8.9	41	35	JUN 25	74	5.9	110	100	155	73	3	30	7	57	19	115	4	852.2

† DATA CORRECTED AFTER PUBLICATION OF THE MONTHLY ISSUE.

Normals, Means, And Extremes

	Temperatures °F							Normal Degree days Base 65 °F		Precipitation in inches											Relative humidity pct.				Wind							Mean number of days											Average station pressure mb.
	Normal			Extremes						Water equivalent							Snow, Ice pellets										Fastest mile $					Sunrise to sunset							Temperatures °F				
Month	Daily maximum	Daily minimum	Monthly	Record highest	Year	Record lowest	Year	Heating	Cooling	Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Maximum monthly	Year	Maximum in 24 hrs.	Year	Hour 05 (Local time)	Hour 11 (Local time)	Hour 17 (Local time)	Hour 23 (Local time)	Mean speed m.p.h.	Prevailing direction	Speed m.p.h.	Direction	Year	Pct. of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Max. (b) 90° and above	Max. 32° and below	Min. 32° and below	Min. 0° and below	Elev. 4839 feet m.s.l.
(a)				36		36					36		36		36		36		36		19	19	19	19	36	15	33	33		36	36	36	36	36	36	36	36	36	19	19	19	19	10
J	36.7	16.5	26.6	60	1971	-23	1963	1190	0	0.64	2.46	1957	T	1961	0.64	1956	33.7	1957	9.1	1957	78	66	63	76	5.6	ESE	54	S	1950	59	6.2	9	7	15	7	3	*	3	0	13	30	4	854.1
F	44.0	23.2	33.6	68	1981	-14	1951	879	0	0.61	1.56	1948	T	1972	0.55	1980	18.4	1948	8.6	1948	70	52	45	65	6.6	ESE	56	W	1967	64	6.1	8	7	13	6	1	*	2	0	2	26	1	853.8
M	52.8	29.6	41.2	81	1971	5	1948	738	0	0.75	2.02	1979	0.02	1972	0.78	1949	14.9	1948	6.1	1948	62	42	35	55	8.4	ESE	65	S	1954	63	6.1	8	9	14	8	1	1	1	0	*	18	0	848.9
A	64.6	38.8	51.7	85	1969	11	1975	404	0	0.79	1.95	1965	0.06	1958	1.33	1965	14.3	1975	8.9	1975	54	33	27	45	9.6	ESE	59	W	1955	68	5.8	9	9	12	6	*	2	*	0	0	7	0	849.7
M	75.8	48.5	62.2	95	1956	26	1970	133	58	0.63	1.79	1957	T	1970	0.74	1973	5.0	1979	5.0	1979	52	30	25	41	9.6	ESE	65	NW	1966	71	5.5	10	10	11	6	*	4	*	1	0	1	0	849.1
J	85.9	56.6	71.3	103	1981	34	1976	20	238	0.55	2.07	1969	T	1980	1.57	1969	0.0		0.0		43	24	19	32	9.8	ESE	66	S	1951	80	3.9	15	10	5	4	0	4	0	14	0	0	0	850.9
J	93.1	64.2	78.7	105	1976	46	1982	0	431	0.46	1.53	1974	0.03	1972	1.42	1974	0.0		0.0		47	28	21	36	9.3	ESE	56	SE	1955	78	4.2	14	12	5	5	0	7	0	26	0	0	0	853.1
A	89.1	61.6	75.4	103	1969	43	1968	0	338	1.05	3.48	1957	0.04	1956	1.21	1953	0.0		0.0		50	31	23	38	9.0	ESE	56	W	1957	76	4.3	14	11	6	7	0	8	0	20	0	0	0	853.1
S	81.3	53.0	67.2	98	1977	29	1978	60	128	0.84	2.81	1982	T	1953	1.35	1965	3.1	1965	3.1	1965	51	33	25	41	9.0	ESE	61	S	1947	79	3.6	17	8	5	5	*	5	0	4	0	*	0	853.4
O	67.9	41.9	54.9	88	1963	18	1975	324	12	0.93	3.45	1972	0.00	1952	1.24	1957	6.1	1975	6.1	1975	57	38	33	50	7.9	ESE	61	NW	1954	73	4.2	15	8	8	5	*	1	*	0	0	3	0	854.3
N	50.9	28.6	39.8	75	1977	-2	1976	756	0	0.61	1.69	1954	0.04	1976	0.82	1974	12.1	1964	8.4	1954	69	51	46	64	6.6	ESE	54	NW	1954	63	5.3	11	7	12	5	1	*	1	0	1	21	*	854.3
D	39.4	19.6	29.5	64	1980	-12	1978	1101	0	0.55	1.89	1951	0.01	1976	1.16	1951	16.7	1967	6.0	1967	76	62	60	74	5.9	ESE	48	NW	1951	60	5.8	10	7	14	6	2	*	2	0	8	30	1	855.2
YR	65.1	40.2	52.7	105	JUL 1976	-23	JAN 1963	5605	1205	8.41	3.48	AUG 1957	0.00	OCT 1952	1.57	JUN 1969	33.7	JAN 1957	9.1	JAN 1957	59	41	35	51	8.1	ESE	66	S	JUN 1951	70	5.1	140	105	120	71	9	33	8	66	24	135	6	852.5

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Maximum monthly precipitation 3.78 in September 1896; maximum precipitation in 24 hours 2.50 in October 1908; maximum snowfall in 24 hours 17.0 in November 1919.

(a) Length of record, years, through the current year unless otherwise noted, based on January data.
(b) 70° and above at Alaskan stations.
* Less than one half.
T Trace.

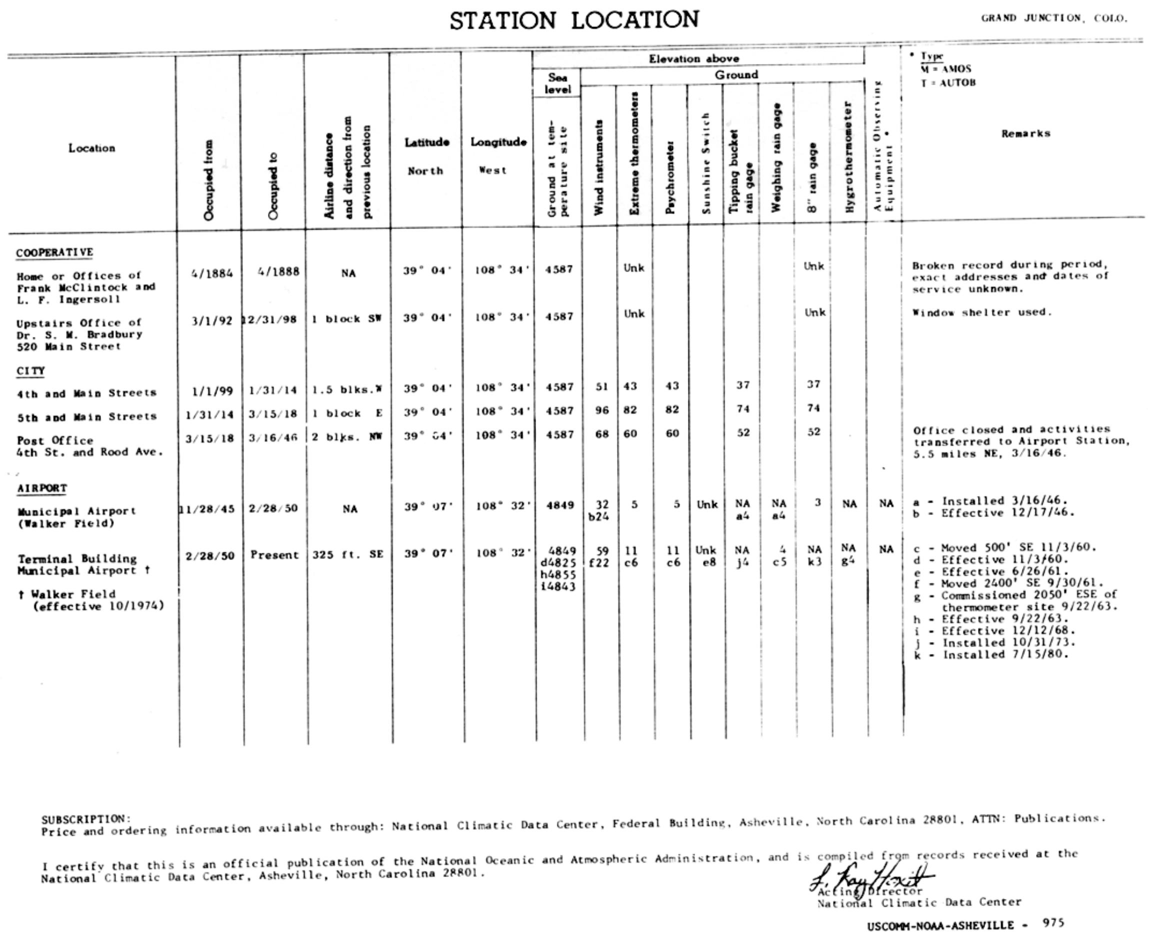
NORMALS - Based on record for the 1941-1970 period.
DATE OF AN EXTREME - The most recent in cases of multiple occurrence.
PREVAILING WIND DIRECTION - Record through 1963.
WIND DIRECTION - Numerals indicate tens of degrees clockwise from true north. 00 indicates calm.
FASTEST MILE WIND - Speed is fastest observed 1-minute value when the direction is in tens of degrees.

$ Through 1979.

IF 312 Supplement to Exercise 5.3

Normally this page contains year-by-year temperature, precipitation, snowfall, and other data. However, the Local Climatological Data 1982 Annual Summary you have in your notebook for Grand Junction, Colorado, starting on page 52 is very difficult to read due to repeated photocopying. I have included here excerpts that you may find useful in Exercise 5.3.

Data for	July	Annual
Normal temperatures °F		
daily maximum temperature	93.1	65.1
daily minimum temperature	64.2	40.2
monthly	78.7	52.7
Extreme temperatures °F		
record highest	105	105
record lowest	46	-23
Relative humidity pct.		
hour 5	47	59
hour 11	28	41
hour 17	21	35
hour 23	36	51
Wind mph		
mean speed	9.3	8.1
fastest mile speed	56	66
Percent of possible sun	78	70
Mean sky cover, tenths	4.2	5.1
Mean number of days		
Sunrise to sunset		
clear	14	140
partly cloudy	12	105
cloudy	5	120
Max temp.		
> 90°	26	66
< 32°	0	24



STATION LOCATION

GRAND JUNCTION, COLO.

Location	Occupied from	Occupied to	Airline distance and direction from previous location	Latitude North	Longitude West	Elevation above									Automatic Observing Equipment *	• Type M = AMOS T = AUTOB
						Sea level	Ground									
						Ground at temperature site	Wind instruments	Extreme thermometers	Psychrometer	Sunshine Switch	Tipping bucket rain gage	Weighing rain gage	8'' rain gage	Hygrothermometer		Remarks
COOPERATIVE																
Home or Offices of Frank McClintock and L. F. Ingersoll	4/1884	4/1888	NA	39° 04'	108° 34'	4587		Unk					Unk			Broken record during period, exact addresses and dates of service unknown.
Upstairs Office of Dr. S. M. Bradbury 520 Main Street	3/1/92	12/31/98	1 block SW	39° 04'	108° 34'	4587		Unk					Unk			Window shelter used.
CITY																
4th and Main Streets	1/1/99	1/31/14	1.5 blks. W	39° 04'	108° 34'	4587	51	43	43		37		37			
5th and Main Streets	1/31/14	3/15/18	1 block E	39° 04'	108° 34'	4587	96	82	82		74		74			
Post Office 4th St. and Rood Ave.	3/15/18	3/16/46	2 blks. NW	39° 04'	108° 34'	4587	68	60	60		52		52			Office closed and activities transferred to Airport Station, 5.5 miles NE, 3/16/46.
AIRPORT																
Municipal Airport (Walker Field)	11/28/45	2/28/50	NA	39° 07'	108° 32'	4849	32 b24	5	5	Unk	NA a4	NA a4	3	NA	NA	a - Installed 3/16/46. b - Effective 12/17/46.
Terminal Building Municipal Airport †	2/28/50	Present	325 ft. SE	39° 07'	108° 32'	4849 d4825 h4855 i4843	59 f22	11 c6	11 c6	Unk e8	NA j4	4 c5	NA k3	NA g4	NA	c - Moved 500' SE 11/3/60. d - Effective 11/3/60. e - Effective 6/26/61. f - Moved 2400' SE 9/30/61. g - Commissioned 2050' ESE of thermometer site 9/22/63. h - Effective 9/22/63. i - Effective 12/12/68. j - Installed 10/31/73. k - Installed 7/15/80.
† Walker Field (effective 10/1974)																

SUBSCRIPTION:
Price and ordering information available through: National Climatic Data Center, Federal Building, Asheville, North Carolina 28801, ATTN: Publications.

I certify that this is an official publication of the National Oceanic and Atmospheric Administration, and is compiled from records received at the National Climatic Data Center, Asheville, North Carolina 28801.

L. Ray Hoxit
Acting Director
National Climatic Data Center

USCOMM-NOAA-ASHEVILLE - 975

LCD page 4

Figure 5.1. Network of stations for which ground level solar radiation is available in Cinquemani et al., 1978.

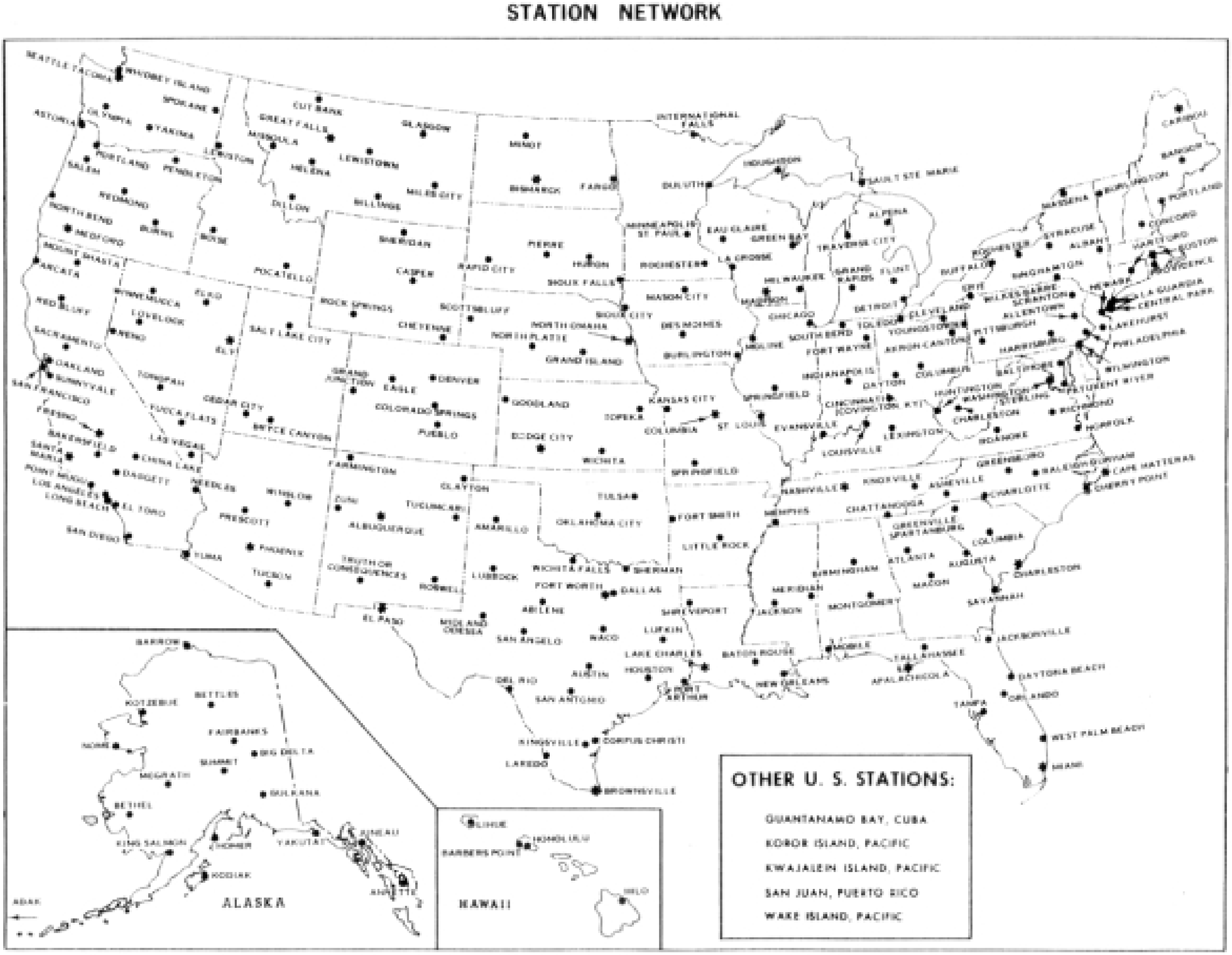


Table 5.1. Extract from Input Data for Solar Systems (Cinquemani et al. 1978).

****

STATION: GRAND JUNCTION STATE: CO

STATION NUMBER: 23066 LATITUDE: 3907N LONGITUDE: 10832W ELEVATION: 1475

	NORMAL TEMPERATURE (DEG F)*			NORMAL DEGREE DAYS* BASE 65 DEG F		TOTAL HEMISPHERIC MEAN DAILY SOLAR RADIATION#		
MONTH	DAILY MAXIMUM	DAILY MINIMUM	MONTHLY	HEATING	COOLING	BTU/FT2	KJ/M2	LANGLEYS
JAN	36.7	16.5	26.6	1190	0	791.3	8980.0	214.6
FEB	44.0	23.2	33.6	879	0	1119.0	12699.0	303.5
MAR	52.8	29.6	41.2	738	0	1553.5	17630.0	421.4
APR	64.6	38.8	51.7	404	0	1986.4	22543.0	538.8
MAY	75.8	48.5	62.2	133	47	2379.8	27008.0	645.5
JUN	85.9	56.5	71.3	20	209	2598.5	29490.0	704.8
JUL	93.1	64.2	78.7	0	425	2465.2	27977.0	668.7
AUG	89.1	61.6	75.4	0	322	2182.0	24763.0	591.8
SEP	81.3	53.0	67.2	60	126	1834.4	20818.0	497.6
OCT	67.9	41.9	54.9	324	11	1345.0	15264.0	364.8
NOV	50.9	28.6	39.8	756	0	918.1	10419.0	249.0
DEC	39.4	19.6	29.5	1101	0	731.3	8300.0	198.4
ANN	65.1	40.2	52.7	5605	1140	1658.7	18824.0	449.9

* BASED ON 1941-1970 PERIOD

\# AS NOTED IN SOLMET VOLUME 1

****

EXERCISE 5.4

1. Look over your map for any other telltale signs related to temperature-related stuff: springs and seeps, wells, levees, gravel deposits, disappearing streams, canals, and gaging stations. Select a stream reach with some relief off of your group's topographic map or your own if self-study.

2. Determine and enter the necessary topographic input values for SSTEMP as best as possible from the map. Invent any values you must have in addition to those from the map.

3. Test the model's sensitivity to changes in the variables.

4. Is there a latitude for your set of variables above which there is no sunrise?

5. What difference does stream width make? Which factors, topographic or vegetative or both, interact with stream width?

6. Test whether the mid-point of a monthly time period adequately characterizes the average of many daily snapshots.

7. What do you think are the limitations of SSTEMP? What are its strengths?

8. As time and interest permits, try the Gray Card and light meter method of calculating vegetative shading. Also try out a clinometer.

9. What phrase best characterizes what shade actually is?

    a. Average percent of stream reach's surface area continuously in shadow during the day.

    b. Average percent of time stream reach's total surface area is in shadow during the day.

    c. Percent of total solar radiation intercepted from reaching the water's surface during the day.

    d. All of the above.

EXERCISE 5.5

1. Select a spot on your map and try the solar radiation prediction portion of SSTEMP.

2. Look in IP #16, pages II-13 and II-14, or IP #13 for representative dust and reflectivity coefficients.

3. Compare your results with those from the USDA maps in the reference section.

4. Test for model sensitivity to the input values.

5. What are the strengths and weaknesses of this portion of the program?

ANSWERS TO EXERCISE 5.3

1. To solve this problem, you will need to calculate many more parameters:

    a. Lateral Temperature -- from the LCD we can find that the average annual air temperature is 52.7°F. We will assume that the lateral flow is the same temperature.

    b. Segment Outflow -- add the accretion to the inflow, as (.0208 * 43.4) + 60.38 = 61.283

    c. Manning's n -- assume 0.035. Additional fieldwork would be required to determine this any better.

    d. Width's A Term -- for the equation $w = aQ^b$, substitute known values. Thus, we have $60.96 = a \cong 60.38^{0.18}$: therefore a = 29.14.

    e. Thermal Gradient -- use 1.65.

    f. Air Temperature -- from the LCD we can see that the average mean daily temperature for July is 78.7 EF and the average maximum is 93.1°F.

    g. Relative Humidity -- from the LCD, you find that the four daily readings 47, 28, 21, and 36%. Average these figures and express them as a percent, 33%, for the answer.

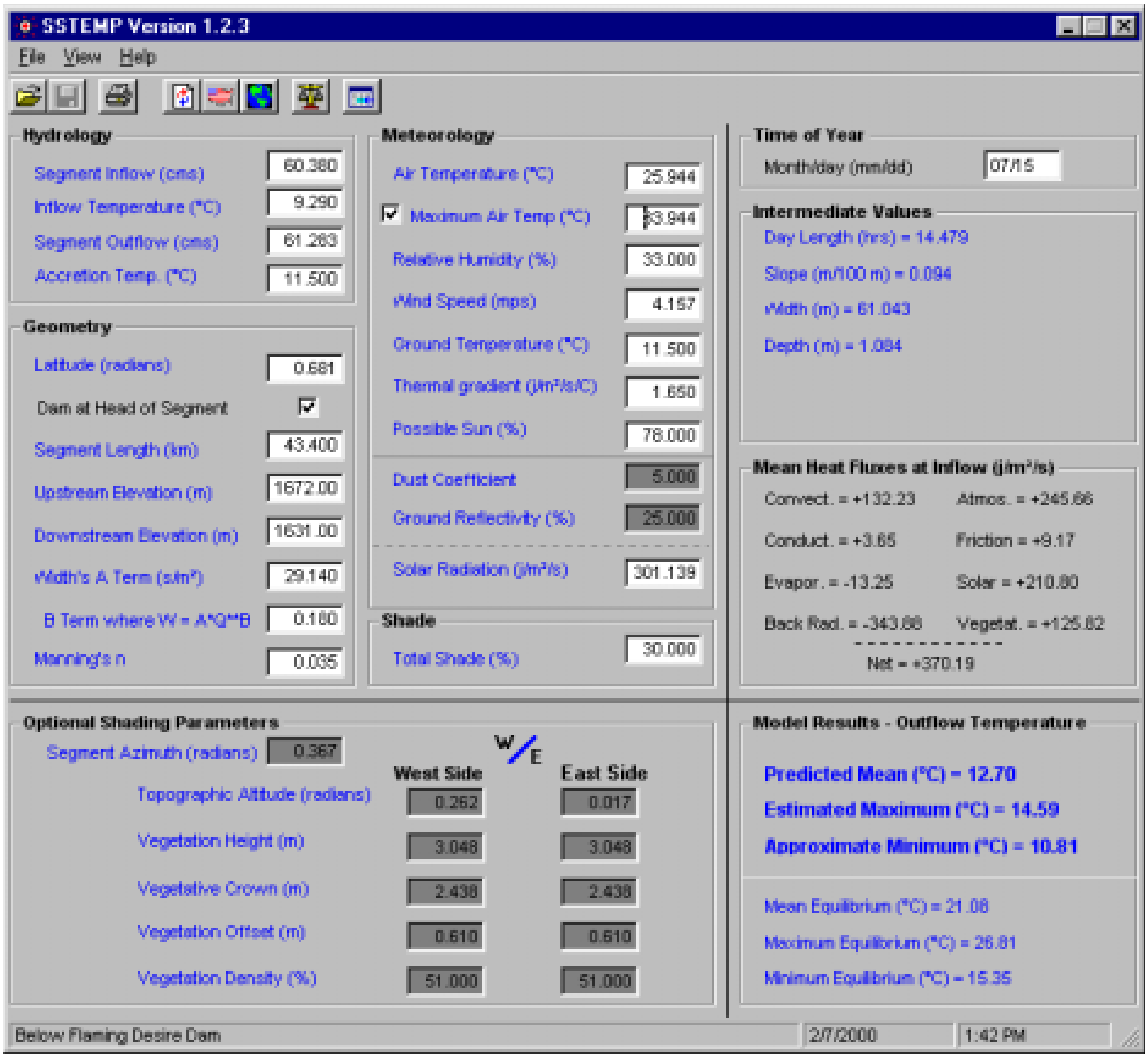
    h. Wind Speed -- from the LCD, calculate that the average wind speed for July is 9.3 mph.

    i. Percent Possible Sun -- again from the LCD, merely express the 78%.

    j. Solar Radiation -- from the Input Data for the Solar Systems, find Grand Junction's July figure of 27977 KJ/M^2. Multiply by 0.011574 to get the proper units. Finally factor in the water penetration of 93% to get 301.139 J/M^2/S/C.

    k. Upstream Dam – yes.

You should get answers that look like:



Hydrology

Segment Inflow (cms)	60.380
Inflow Temperature (°C)	9.290
Segment Outflow (cms)	61.283
Accretion Temp. (°C)	11.500

Geometry

Latitude (radians)	0.681
Dam at Head of Segment	☑
Segment Length (km)	43.400
Upstream Elevation (m)	1672.00
Downstream Elevation (m)	1631.00
Width's A Term (s/m²)	29.140
B Term where W = A*Q**B	0.180
Manning's n	0.035

Meteorology

Air Temperature (°C)	25.944
☑ Maximum Air Temp (°C)	33.944
Relative Humidity (%)	33.000
Wind Speed (mps)	4.157
Ground Temperature (°C)	11.500
Thermal gradient (j/m²/s/C)	1.650
Possible Sun (%)	78.000
Dust Coefficient	5.000
Ground Reflectivity (%)	25.000
Solar Radiation (j/m²/s)	301.139

Shade

Total Shade (%)	30.000

Time of Year

Month/day (mm/dd)	07/15

Intermediate Values

Day Length (hrs) = 14.479

Slope (m/100 m) = 0.094

Width (m) = 61.043

Depth (m) = 1.084

Mean Heat Fluxes at Inflow (j/m²/s)

Convect. = +132.23	Atmos. = +245.66
Conduct. = +3.65	Friction = +9.17
Evapor. = -13.25	Solar = +210.80
Back Rad. = -343.88	Vegetat. = +125.82

Net = +370.19

Optional Shading Parameters

Segment Azimuth (radians)	0.367

W/E	West Side	East Side
Topographic Altitude (radians)	0.262	0.017
Vegetation Height (m)	3.048	3.048
Vegetative Crown (m)	2.438	2.438
Vegetation Offset (m)	0.610	0.610
Vegetation Density (%)	51.000	51.000

Model Results - Outflow Temperature

Predicted Mean (°C) = 12.70

Estimated Maximum (°C) = 14.59

Approximate Minimum (°C) = 10.81

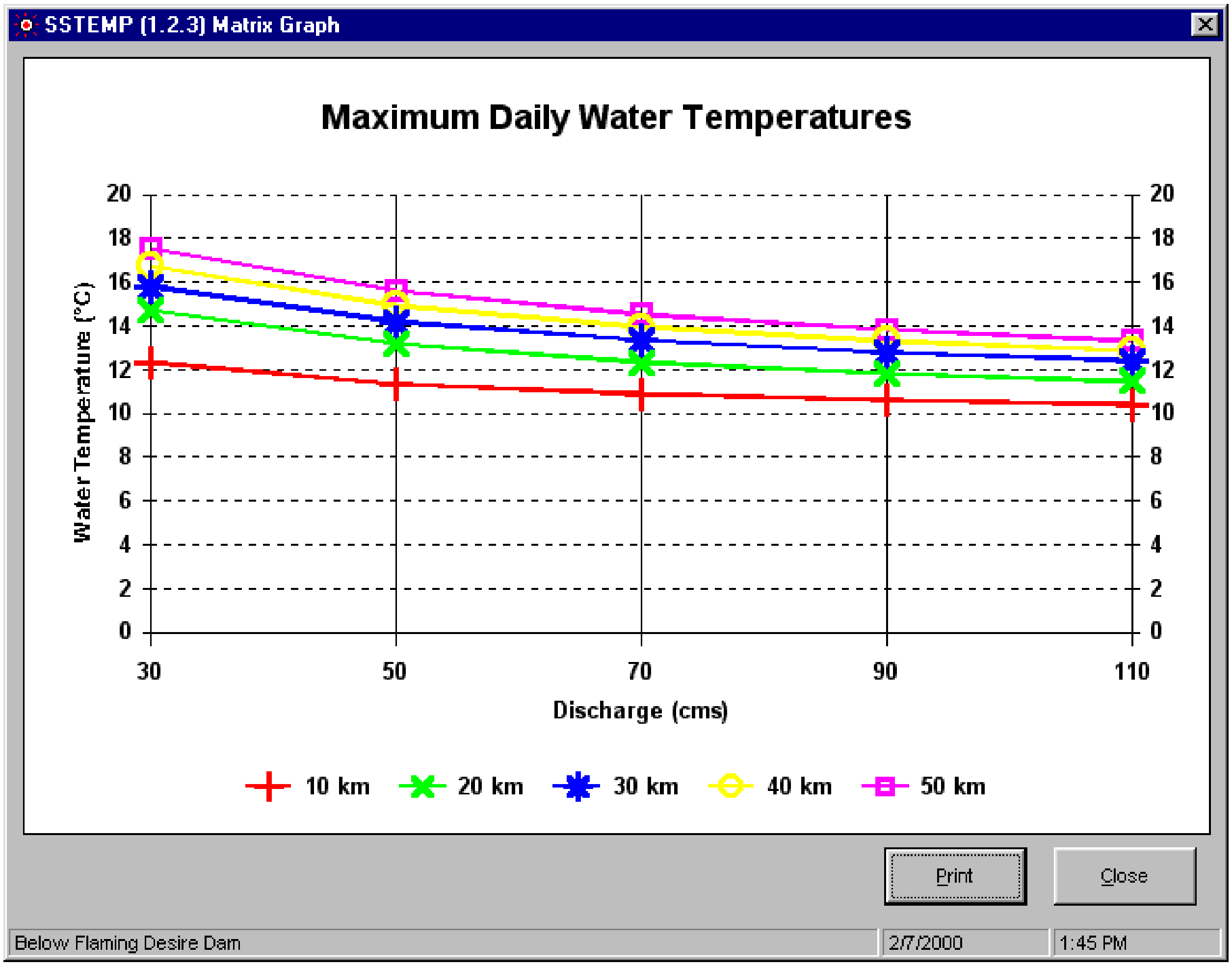
Mean Equilibrium (°C) = 21.08

Maximum Equilibrium (°C) = 26.81

Minimum Equilibrium (°C) = 15.35

Below Flaming Desire Dam | 2/7/2000 | 1:42 PM

2.



Below Flaming Desire Dam | 2/7/2000 | 1:45 PM

3. Many things can happen separately or in combination to disrupt your fishery. For example, if the flow were cut to a paltry 16 cms, or if the discharge temperature reached 16°C or if the air temperature were a torrid 39°C, your maximum of 18° would be exceeded. Similarly, there would be low temperature problems if the flow were increased, etc.

   The fishery could be maintained for a remarkable 140 kilometers, but would the "average" stream geometry and meteorology conditions remain the same?

4. A simple mixing may be performed by using the mixing equation II (118) on page II-55 of the Information Paper 16.

5. a. Discharge and width
   b. Length and elevation
   c. Cloud cover and radiation
   d. Daylight and radiation
   e. Manning's n and discharge

f. Maybe others too

ANSWERS TO EXERCISE 5.4

5. Should be the Arctic Circle, latitude about 67°.

6. Width only matters for vegetative shade. Topographic shading is insensitive to changes in width -- try it. In contrast, shading is sensitive to the width of the stream and the offset of vegetation from it.

7. Should get about the same answers.

8. Limitations: (1) English only; (2) non-dynamic width.
Strengths: (1) Simplicity; (2) ease of learning.

10. Though “All of the above” may be correct for some streams, answer C is probably the best choice in the context of the temperature models as it more accurately reflects what is going on in the program.

ANSWERS TO EXERCISE 5.5

5. See answer 8, above.

RULES OF THUMB

> "There is nothing new under the sun, but there are lots of old things we don't know."
> - Ambrose Bierce

One hundred years ago 50 to 55 degrees was considered a good house temperature. Fireplaces provided the heat in those days. When stoves came into use, about 90 years ago, the temperature rose to 62 degrees. With the increasing use of furnaces, some 50 years ago, a heat of 72 degrees was quite usual. Today a temperature of 70 degrees is considered standard.

RESOURCES FOR FURTHER LEARNING

Should you get interested in learning more about these methods and programs, you may wish to pursue the following literature from which most of the above material was derived:

Bartholow, J. M. 1989. Applied stream temperature analysis: Field and analytic methods. Instream Flow Information Paper 13. Aquatic Systems Branch. Biological Report 89(17). 139 pp.

Cinquemani, V., J. R. Owenby, and R. G. Baldwin. 1978. Input data for solar systems. U.S. Department of Energy. Environmental Resources and Assessment Branch. 192 pp.

Leopold, L. B., M. G. Wolman, and J. P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman & Company. 522 pp.

National Oceanic and Atmospheric Administration, Department of Commerce, National Climatic Data Center, Federal Building, Asheville, N.C. 28801 (source of LCD’s).

Platts, W. S. 1990. Managing fisheries and wildlife on rangelands grazed by livestock. Don Chapman and Associates (in conjunction with the Nevada Department of Wildlife). Boise, Id. v.p.

U.S. Department of Commerce. 1983. Climatic atlas of the United States. National Climatic Data Center. Asheville, N.C. 80 pp.

TOPIC #6: FAMILIARITY DOESN'T BREED CONTEMPT

Time:	1-2 hours
Format:	Homework
Assignment:	(1) Skim parts I and II of IP#16. (2) Incorporate errata in the body of IP#16. (3) Look through remaining course material. (4) Be prepared to ask questions tomorrow morning
Objectives:	Familiarization with location of information throughout the course material.

TOPIC #7: QUESTIONS FROM DAY 1

Time: 0.25 hours
Format: Discussion
Assignment: Be prepared to ask questions.
Objectives: Clarity, perspective, and understanding.

After the first full day, covering Topics 1B5, students typically begin to question several things. Although the question/answer session is meant to be free roaming, it is a good idea to make sure that there are no outstanding questions on input parameter definitions. Some students begin to feel uncomfortable about the predictive ability of the models; that is, they understand simulating existing conditions but don’t quite get the feel for a “what if” analysis. In addition, averaging meteorological values such as shade and solar radiation over a full day (or whatever averaging period) may seem mysterious.

If you are taking the self-study class, take a moment and e-mail any questions to the instructor.

TOPIC #8: LAY OF THE LAND:
SPATIAL DESCRIPTION OF STREAM NETWORK LAYOUT

Time:	1 hour
Format:	Lecture/Reading
Assignment:	Review notebook material
Objectives:	(1) Introduce three major logical components of temperature model. (2) Define all node types and cover their connectivity.

NOTE: The following is a modified arrangement of the text originally appearing in Information Paper #16, pages III-63 to III-94. Corrections and supplements have been made where appropriate.

Organization of SNTEMP Data

General data requirements. The data required by the SNTEMP model includes job control information, six other required input data sets, and an optional seventh data set. The input data sets are: (1) stream geometry data; (2) time period information; (3) meteorology information; (4) study node information; (5) hydrology node information; (6) hydrology data at the hydrology nodes; and (7) shade data (optional). A node is a system descriptor point that defines what process is to be simulated at that location within the network.

The **stream geometry data** consist of a *network definition* of the stream system (mainstem and tributaries), including site *location* (distance upstream from some arbitrary downstream site), and the stream geometry, including *latitude, elevation, Manning's n or travel time* values, *stream width, shading data, ground temperature*, and *streambed thermal gradient*. The **time period data** include *time step* information, *dust and ground reflectivity* parameters, and *calibration factors* by time period for air temperature and wind speed. The required **meteorological data** are *air temperature, wind speed, relative humidity*, and *percent possible sunshine*. *Observed solar radiation* at ground level is optional. Many items have default values built in or assumed, i.e., if you don't specify them yourself.

Study node information includes site location information for points where *output* predictions are desired and not otherwise available. **Hydrology node** information includes site location information for points in the system where hydrology data are required. Hydrology information at the hydrology nodes includes *discharge, stream temperature* for certain node types, *lateral inflow temperature*, and *upstream discharge* at any internal (flow-through) reservoirs in the system.

Shade data are required if the stream shade model is to be used to calculate riparian and topographic shading of the stream. Shade data include *site latitude, site azimuth* (orientation), *stream width*, and the vegetative parameters, *vegetation height, crown measurement, vegetation offset*, and *vegetation density*.

In addition to these data sets, there is a master **job control** data set that defines the temporal extent of the job to be run and desired output produced.

Defining Your Network

1. Begin with the end in mind. As best as you can, have a clear statement of the biological problem(s) and objective(s). This will help make every later decision more clear.

2. Tentatively identify study area

    a. Identify sections of stream with biological importance.
    b. Add stream sections/features necessary for full range of management control.

3. Begin consideration of temporal periods of interest

    a. Is there a critical week/day in a season?
    b. What seasons are important?
    c. What kind of time step is necessary? We will cover how these questions impact the study area (length of stream) in a later topic.

4. Sketch your network layout to incorporate target sections of stream and include other nodes that may be necessary. Then define the **Skeleton Network.** The stream system network is defined by the proper ordering of node types. Initially, a stream system **skeleton** (bare bones) network is defined by the following nodes:

    (1) **H** (Headwater) - The upstream boundary of the mainstem and each tributary. Usually at a gage or a "zero flow" headwater, i.e., a point of essentially no flow.

    (2) **S** (Structure) - A point (reservoir) at a headwater or within the stream network that may have a discontinuity in discharge and will have a release temperature controlled or defined by the user. There are two kinds of structures: "headwater" and internal. Headwater, as the name implies, forms an upstream boundary condition, while an internal structure is a flow-through reservoir.

    (3) **B** (Branch) - The point on the mainstem immediately upstream of a tributary confluence.

    (4) **T** (Terminal) - The last point of a tributary before joining with a mainstem.

    (5) **J** (Junction) - The point on the mainstem just below a tributary confluence. Note that mixing is straightforward:

    $$T_J = [(Q_B * T_B) + (Q_T * T_T)] / Q_J$$

    Where the subscript **J** is junction, **B** is branch, and **T** is terminal, and the large T and Q are temperature and flow respectfully. Note that the equation may be rearranged to solve for whatever is the missing element, often quite usefully.

    (6) **E** (End) - The network end point; i.e., the node farthest downstream.

The skeleton network is the *minimum* number of nodes needed to define the network and is assembled once at the beginning of a particular study. The system may be represented by a schematic diagram that identifies the locations of these nodes in relation to one another with stream distances increasing upstream from a common point. The mainstem and tributary headwaters are generally chosen to coincide with locations having historical flow and temperature data or are the actual headwater sources near a point of zero discharge.

The following steps can be used to define the skeleton network:

1. Draw a schematic diagram of the network.

2. Select a system endpoint (**E** node, usually with a distance of 0.0).

3. Select the network's mainstem (usually the true mainstem) and start at the top.

4. Proceed downstream on the current mainstem (or tributary) until a structure (reservoir) or tributary is encountered.

If a structure is encountered, insert a node point with an **S** node type.

If a tributary is encountered, then,

(a) Insert a **B** node on the current mainstem (or tributary) with the same distance as the tributary confluence.

(b) Insert a starting **H** or **S** node for the tributary.

(c) Repeat step 4 above until the end of the tributary.

(d) At the end of the tributary, insert a **T** node.

(e) Insert a **J** node for the previous mainstem or tributary and proceed downstream.

(f) Repeat this procedure until the system endpoint (**E** node) is reached.

At this point, you will have defined the skeleton network, looking something like the major black dots in Figure 8.1.

Next put flesh on the skeleton network. Once a common skeleton network is defined, additional node types may be added to locate points where additional hydrology, stream geometry, and output request information is available or necessary.

Additional **hydrology nodes** that may be included are:

(7) **Q** (Discharge) - A node within the network that is used to redefine the quantity of instream (and therefore lateral) flow.

(8) **V** (Validation or Verification) - A node where the temperature is known and can be compared to predicted temperatures.

(9) **K** (Calibration) - A node where the temperature is known and will be used for updating the water temperature information. It is recommended that **K** nodes not be used except under very special circumstances.

(10) **D** (Diversion) - A node from which water is to be diverted from stream.

(11) **P** (Point load) - A node where a point load discharges into the river at a known temperature.

(12) **R** (Return) - A node where diverted flow returns as a point discharge into the river.

Other reach definitions and output nodes include:

(13) **C** (Change) - The upstream end of a reach with new hydraulic or stream shading properties.

(14) **O** (Output) - A node where output is needed from model.

The model automatically adds **M** (Meteorology) nodes at 300-m elevation intervals if your network has a vertical gap of more than 300 m. This allows for a more precise translation of single set of meteorology data at central weather station to on-stream locations.

Examine Figures 8.1a and 8.1b to see if they make sense in terms of translating “real world” plumbing into a schematic representation.

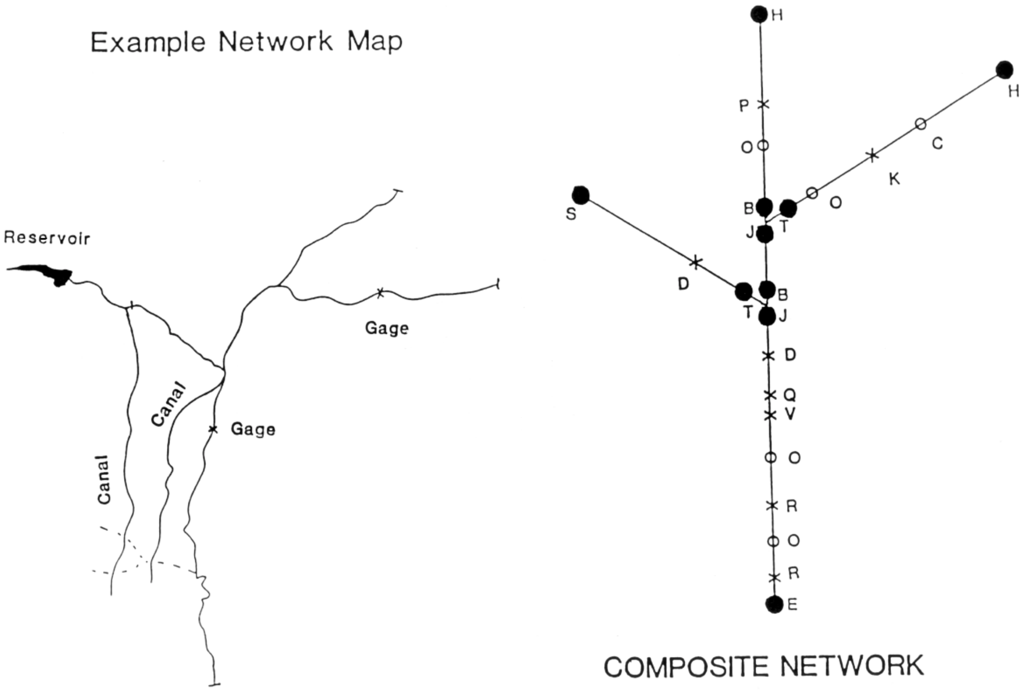


Figure 8.1. “Real world” map and its schematic representation in SNTEMP’s node types. Black dots represent the skeleton nodes, X-marks are hydrology nodes, and O-marks are O and C nodes.

RULES OF THUMB

> "It is better to know nothing than to know what ain't so." – Josh Billings

Remember the above when thinking about SNTEMP's defaults. They work pretty well most of the time. You can do better, but don't put in bad stuff.

Strange but true, typical applications of SNTEMP usually have about 30 nodes, almost regardless of the spatial extent of the network. Don't let this determine what you do, but just keep it in mind.

SUGGESTED READINGS FOR TOPIC 8

Information Paper #16

Dinan, K. F. 1992. Application of the Stream Network Temperature Model (SNTEMP) to the central Platte River. Professional paper, Department of Fish and Wildlife, Colorado State University, Fort Collins, Colorado. 49 pp. plus appendix.

REVIEW QUESTIONS FOR TOPIC 8

1. Given what you know about SNTEMP’s node types, how would a stream with multiple braided channels be modeled?

2. Of all the nodes, **Q**, **V**, and **K** seem to cause the most confusion. Can you explain each of these nodes, why they may be used, and any problems associated with them?

ANSWERS TO TOPIC 8

1. SNTEMP cannot directly model braided streams; the model assumes a strict linear but dendritic hierarchy. There is a new option to pass diverted water from a **D** node to another arbitrary hydrology node (without intervening heat flux), but it is sort of a kludgy add-on. One river, the Platte in Nebraska, was modeled (Dinan 1992) with great difficulty by developing empirical relations about how much flow was in each channel at different stages and essentially modeling the channels independently, then merging them “by hand.” If you really need to do this type of modeling, the Branched Lagrangian Transport Model (BLTM) model, I think, may do this a lot better. See Topic 32 for more on BLTM.

2. Discussion.

TOPIC #9: HOW TIME FLIES:
TEMPORAL DESCRIPTION OF STREAM TEMPERATURE MODEL

Time:	0.5 hours
Format:	Lecture/Reading
Assignment:	Review notebook material.
Objectives:	(1) Understand averaging periods and what that means for data collection. (2) Understand theoretical constraints on model application.

SNTEMP's Time Step

Hydraulic engineers classify flow problems as **steady state** or **dynamic**. Steady flow means that stream flow is essentially unchanging over a specified time interval at a given location. In contrast, dynamic flow you might imagine is not steady -- it changes over time. For our purposes, dynamic flow is principally hydropeaking, where flows may vary greatly within a single day, or perhaps within an hour. Obviously, there is a large spectrum of dynamic flow, all the way from extreme hydropeaking to moderated ramping hydropeaking, to daily irrigation withdrawals, to daily snowmelt, to daily evapotranspiration variations. Any can be large or small with respect to the "base" flow or "minimum" flow, and with respect to the period over which changes occur. Unfortunately, there is no hard-and-fast rule for distinguishing steady from dynamic flow; it is always a matter of degree. Flows can be gradually varying in SNTEMP.

For SNTEMP's purposes, the period over which any changes occur will be referred to as the **averaging period**. SNTEMP can support averaging periods from a minimum of one day to 366 days, though typically multi-day periods are either seven days or one month. All processes that happen within that interval are averaged for SNTEMP. In other words, in a weekly time-step, a steady flow representation of a system cannot "see" a two-day duration flood that happened some time within that week. Similarly, a daily time-step model cannot be used to evaluate the effects of a peaking power release.

To up the ante, SNTEMP is referred to as an **average mean daily model**. This means that the model produces estimates (or predictions) for the daily mean water temperatures averaged over the averaging period. Said another way, if the model were a weekly model, the output would represent mean daily water temperatures for an average day within that week. This means that all the inputs to SNTEMP are averaged over the same averaging period, e.g., a day, a week, or a month. Thus, as mentioned above, the 2-day freshet that occurred within a week gets lost in the averaging for flow. Similarly, as far as cloud cover goes, a 24-hour period that is clear all night and cloudy all day looks the same to SNTEMP as a 24-hour period that is cloudy all night and clear all day. This averaging is one source of error in SNTEMP.

Because events and processes are averaged for the averaging period, this implies that SNTEMP is a steady state model. It does not mean that dynamic problems cannot be simulated, but it does mean that the dynamics will be lost, the highs and lows will be averaged out. If your objectives include the analysis of hydropeaking, you must seek a different model.

For SNTEMP, the **travel time** for water from the most upstream node to the most downstream node (**E** node) should be less than the model's averaging period. Since travel time is longest (i.e., velocity is slowest) at low flow, and it is usually imperative to have a good model that well represents the low flow-high temperature conditions, the maximum extent of your study area may need to shrink or the time step lengthen. This is because the heat flux model, being an average model, “looks” at the stream in steady state. For example, if today’s mean water temperature in a given reach is partially controlled by what transpired meteorologically speaking yesterday, the model is invalid. Said a different way, all the water in the network must enter and exit within one averaging period.

To get around this limitation, one could develop two or more spatially distinct models with temperature predictions from one model cascading from one to another. This would be a big hassle unless you wrote some automatic procedure to accomplish this feat. Alternately, as mentioned, one lengthens the averaging period to two days, one week, etc. One final tidbit, there is some small bit of evidence that SNTEMP performs best when the travel time through the study area exactly matches the averaging period.

The more you bend any of the above rules, the worse the model can be expected to perform. These words of wisdom are not meant to scare anybody off. The model will likely perform fairly well for a whole variety of less-than-perfect conditions. Just keep your eyes open.

In summary, SNTEMP is a **steady state**, **average mean daily model**. Steady state refers not only to flow, but to all input and output to and from the model. The **travel time** of water through the network should be within a single **averaging period**. The more any of these rules are broken, the poorer the performance of the model.

RULES OF THUMB

> "You could not step twice into the same rivers; for other waters are ever flowing on to you." - Heraclitus

See the Q&A session below.

What's the best method for computing mean daily temperatures? Unless it is all you have, rather than use the daily maximum and minimum, it is best to take all the daily sample values, of whatever interval, and average them. For example, if your instrumentation were set to sample hourly, you would take all 24 values and average them. This applies to all values, be they water or air temperature, or other meteorological variables. Simply taking the (maximum-minimum)/24 introduces a seasonal bias, usually less than 1.0°C, but a bias nonetheless.

For air temperature only, a good approximation to the mean daily temperature is (7am + 2pm + 9pm +9pm)/4. (Sunrise + 2 pm + 9pm)/3 works well too. I am unaware of similar rules of thumb for water temperature.

SUGGESTED READINGS FOR TOPIC 9

The following article sheds some light on the network extent problem and discusses other basin temperature models.

Sullivan, K., J. Tooley, K. Doughty, J. E. Caldwell, and P. Knudsen. 1990. Evaluation of prediction models and characterization of stream temperature regimes in Washington. Timber/Fish/Wildlife Rep. No. TFWBWQ3B90B006. Washington Dept. Nat. Resources, Olympia, Washington. 224 pp.

The following article is an example of how all the steady state rules were broken for an analysis of hydropeaking:

Waddle, T. J. 1988. Water temperature data analysis and simulation for the Salmon River, New York, Summer 1986. Pages 201B211 *in* H. J. Morel-Seytoux and D. G. DeCoursey, editors. Proceedings of the eighth annual AGU front range hydrology days, Water Resources Publication 1988.

REVIEW QUESTIONS FOR TOPIC 9

1. Though we haven’t covered calibration of SNTEMP, what's your guess: is the model likely to perform better (closer agreement between simulated and field-observed temperature values) for a daily model, weekly model, or monthly model? Why?

2. But wait, you say. You've really got to get a handle on what happens during hydropeaking. What if I model the highest flow that occurs during the averaging period and model the lowest flow? Could I then “bracket” the temperatures that are likely to occur? Yes or No?

ANSWERS FOR TOPIC 9

1. Averaging removes the extremes. Thus, the longer the averaging period, the greater the likelihood the model and the field measurements will agree closely. The shorter the averaging period, the more the extremes will be present and the more likely the model will miss. Consider the cloudy day versus the cloudy night example mentioned above. Both days look the same to SNTEMP, but have obvious consequences for daily water temperature, especially the maximum. The model will overestimate water temperatures for the cloudy day and will under estimate for the cloudy night. But including them both in a single averaging period will smooth the wrinkles.

2. Yes. This is possible, but one cannot say for sure that any temperature is any more likely than another within the range so derived.

TOPIC #10: MOVE IT:
TRANSPORT OF WATER AND HEAT WITHIN THE STREAM TEMPERATURE MODEL

Time: 1 hour
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand boundary conditions and forcing functions.
(2) Understand why the SNTEMP model is not a hydrology model.
(3) Understand the limitations of SNTEMP's maximum temperature calculations.

1. Heat is transported by flow, so it is important to get the flows right or you will not get the temperatures right.

    a. Water moves downstream between hydrology nodes, **H, B, T, S, J, Q, K, V**, and **E**.

    b. Thermal mixing takes place at **J**, **R**, **P** nodes.

    c. Lateral inflow, computed as simple flow differences between upstream and downstream hydrology nodes, is continuously mixed with the stream.

    d. All flow values for nodes are supplied from outside the model for all hydrology nodes:

        1. Stream flow data must be supplied for **H**, **B**, **S**, **T**, **Q**, **K**, **V**, and **J** nodes. One exception is the "zero flow headwater" for which one assumes zero flow and no perceptible water temperature, letting normal heat flux processes operate from that point downstream.

        2. Diversion (**D**) and Return (**R**) flow discharges are not connected in the model. That is, no heat flux occurs between **D** and **R** nodes; in fact, the model knows nothing about connections, with one exception described later.

        3. Internal **S** nodes (not headwater **S** nodes) must have both inflow and outflow specified.

        4. All flows supplied are assumed to be correct. If they are not, improper mixing leads to bad temperature predictions because the *heat* is not maintained correctly.

2. Water temperature values must be supplied at:

    a. Non-zero flow headwaters (**H** & **S** Nodes)

    b. **P**, **V**, **K** nodes

    c. **R** - or a blank value will *default* to equilibrium temperature.

    d. **S** - release temperature must be supplied as model essentially starts over at a structure. There is, however, an option to compute an equilibrium release temperature.

    e. **NOTE** that **J** nodes do not need temperature data as the model mixes from upstream **T** and **B** nodes.

3. Data Sources

    a. *Flow*

        1. USGS and other agency gage records can be used for **H**, **S**, **Q**, **K**, **V**, **B**, **T**, **E** node flows; also see HYDRODATA and EARTHINFO.

        2. **D**iversions, **R**eturn flows, **P**oint sources, etc., from water users, state engineer, or model estimates.

        3. There are usually not enough gages to define flows at all nodes in a network so known flows must be distributed to the other nodes using a replicable process; choices are:

            a. Write a separate distribution model as in IP#16. One could use a drainage area ratio technique, or perform a linear distribution, or some combination. Consult a hydrologist;

            b. Use an existing routing hydrology model that has been calibrated for the basin, e.g., the Stanford Watershed Model (SWM);

            c. Perform similar routing hand calculations for small studies.

    b. *Temperature*

        1. USGS and other agency gage records, hatchery records, municipal intakes, etc., for **H**, **S**, **Q**, **K**, **V**, **B**, **T**, **E**, **C** nodes; also see HYDRODATA and EARTHINFO.

        2. **P** nodes from water user or discharger.

        3. **R** nodes must usually be based on assumptions unless gaged.

4. Maximum Temperatures

Both the SSTEMP and SNTEMP models suffer from the disadvantage of less than perfect maximum temperature predictions. SNTEMP was developed to predict mean daily temperatures; the entire mathematical basis was simplified for this purpose. Maximum daily temperature estimation was perhaps something of an afterthought and suffers from the following problems:

a. The calculations are empirical, not theoretical. It is a matter of coaxing an instantaneous maximum temperature out of a daily average model. Theurer et al. (1984, pages II-30 to II-32), derive a way to estimate average afternoon air temperature, the major component of estimating maximum daily water temperature. Regression coefficients were determined for **normal** meteorological conditions at 16 selected weather stations around the country. (Normal has a specific meaning in this context. It is the arithmetic mean of a historical data set, usually represented by the previous 30-year period.) Table II-3 (in Theurer et al. 1984) shows the R-values, standard deviations, and probable differences for each of the 16 stations and for all stations combined. Each of these three statistics is noticeably poorer for all stations combined than for most of the individual stations. This means, no surprise, that we are not sampling from the same underlying distribution in creating the coefficients for the whole set. This is evident in the regression coefficients (a0, a1, a2, and a3), which are highly variable, often by an order of magnitude, as well as varying from positive to negative. This can be improved by performing the same regression for your local study area's meteorology. There is a provision to substitute your own coefficients in the job control file. **Note** that SSTEMP has been improved to allow you to supply the maximum daily air temperature.

b. Updating the regression coefficients, however, is not likely to fully correct the maximum daily water temperature calculations in areas within about six hours travel time from either reservoirs or major tributaries with markedly different mixing temperatures. The reason is that SNTEMP doesn't "know" anything about upstream conditions in predicting maximum temperatures. The program extends the current reach's stream geometry "indefinitely" upstream to simulate the conditions through which the water must travel from solar noon (assumed mean daily water temperature) to solar sunset (assumed maximum daily water temperature). This in itself is a major limitation of the model, only partially corrected in the SSTEMP program by the addition of the *Dam at head of segment* switch.

c. The distance the model looks upstream to find the water at solar noon is a function of flow, width, and Manning’s n, all of which are average values. Many people have a feel for Manning’s n values only by experience with one of the Midcontinent Ecological Science Center hydraulic simulation models, IFG4. Such experience, however, may be misleading because the Manning’s n values in IFG4 are really not hydraulic retardance values at all, but rather act as velocity adjustment factors - - a nice name for a fudge factor. Manning’s n values derived from a water surface profile (WSP) type simulation are likely to be much more representative. Consultants from Woodward Clyde have told me that measurements of Manning’s n from hydraulic simulations can be “very inaccurate” compared with actual measurements from time-of-travel studies. The fact that n or travel time both vary with discharge, especially at low flows, confounds the situation, and no provision is made in the models to do so. One could, of course, make multiple runs using different n values.

Each of the above reasons taken independently, and certainly combined, means that one should always treat the maximum daily water temperature predictions from SNTEMP with care and should subject the predictions to validation. It would be nice to enhance SNTEMP to directly enter readily available maximum daily air temperatures, but it has never been a high enough priority. [Show us the money.]

Corrections for the regression coefficients and Manning’s n should both help. Neither, however, will eliminate the problem with “looking” upstream. This is an area for improvement in the programs. Indeed, Woodward Clyde Consultants have apparently made proprietary improvements to the maximum temperature algorithms by changing the way the model “remembers” what is upstream. Their improvements show better correspondence with observations (Voos, pers. comm.). Even with these changes though, the models leave something to be desired.

The bottom line is that if maximum temperatures from SNTEMP prove unsatisfactory with the incorporation of localized a0 to a3 coefficients, the development of a regression model that includes the mean daily water temperature and appropriate meteorological parameters in a fashion similar to the approach outlined in Theurer et al. (1984) is in order. Standard statistical techniques for inclusion or exclusion of parameters should be done. Occasionally, innovative approaches will be required.

In summary, SNTEMP is not a hydrology model. Accurate flows must be assigned at all boundaries and mixing locations. Water temperatures must be assigned at all boundary locations. The single exception is the “zero flow headwater.” Maximum temperature predictions require extra calibration to be accurate, and may never be very good at certain locations in the network.

RULES OF THUMB

Be careful and scrutinize your output. Don't forget that Manning's n may be used as a calibration factor. See the Temperature Model FAQ at http://www.mesc.usgs.gov/sre/sntemp_faq/sntemp_faq.htm.

SUGGESTED READINGS FOR TOPIC 10

Theurer, F. D. 1985. Heat transport equation for the instream water temperature model. Pages 372-377 *in* Proceedings of the Natural Resources Modeling Symposium. Agricultural Research Service ARS-30, April 1985.

Theurer, F. D., K. A. Voos, and W. J. Miller. 1984. Applications. Part II *in* Instream water temperature model. Instream Flow Information Paper 16. U.S. Fish and Wildlife Service. FWS/OBS-84/15. approx. 200 pp.

REVIEW QUESTIONS FOR TOPIC 10

Why do we emphasize that SNTEMP is not a hydrology model? Using what you know about the mixing equation, show why this is so important.

ANSWERS FOR TOPIC 10

The mixing equation is:

$$T_J = [(Q_B * T_B) + (Q_T * T_T)] / Q_J$$

Look at what happens if any of the Q values is incorrect.

TOPIC #11: COOKING IT: METEOROLOGICAL INFLUENCES

Time: 1 hour
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Introduce meteorological data requirements.
(2) Understand the definition of meteorological variables.
(3) Understand representativeness considerations in met data.

Heat flux simply mean the rate of change in heat over a specified period of time. For our purposes, flux is measured in units of energy per surface area per time. The basic equation for heat flux used for SNTEMP is:

NET HEAT FLUX = + SOLAR RADIATION

+ ATMOSPHERIC RADIATION

+ VEGETATIVE (AND TOPOGRAPHIC) RADIATION

+ EVAPORATION

+ CONVECTION

+ CONDUCTION

+ FRICTION

- WATER’S BACK RADIATION

Figure 11.1. Basic heat flux components considered by SNTEMP.

Let's go into more detail on those components related to meteorology.

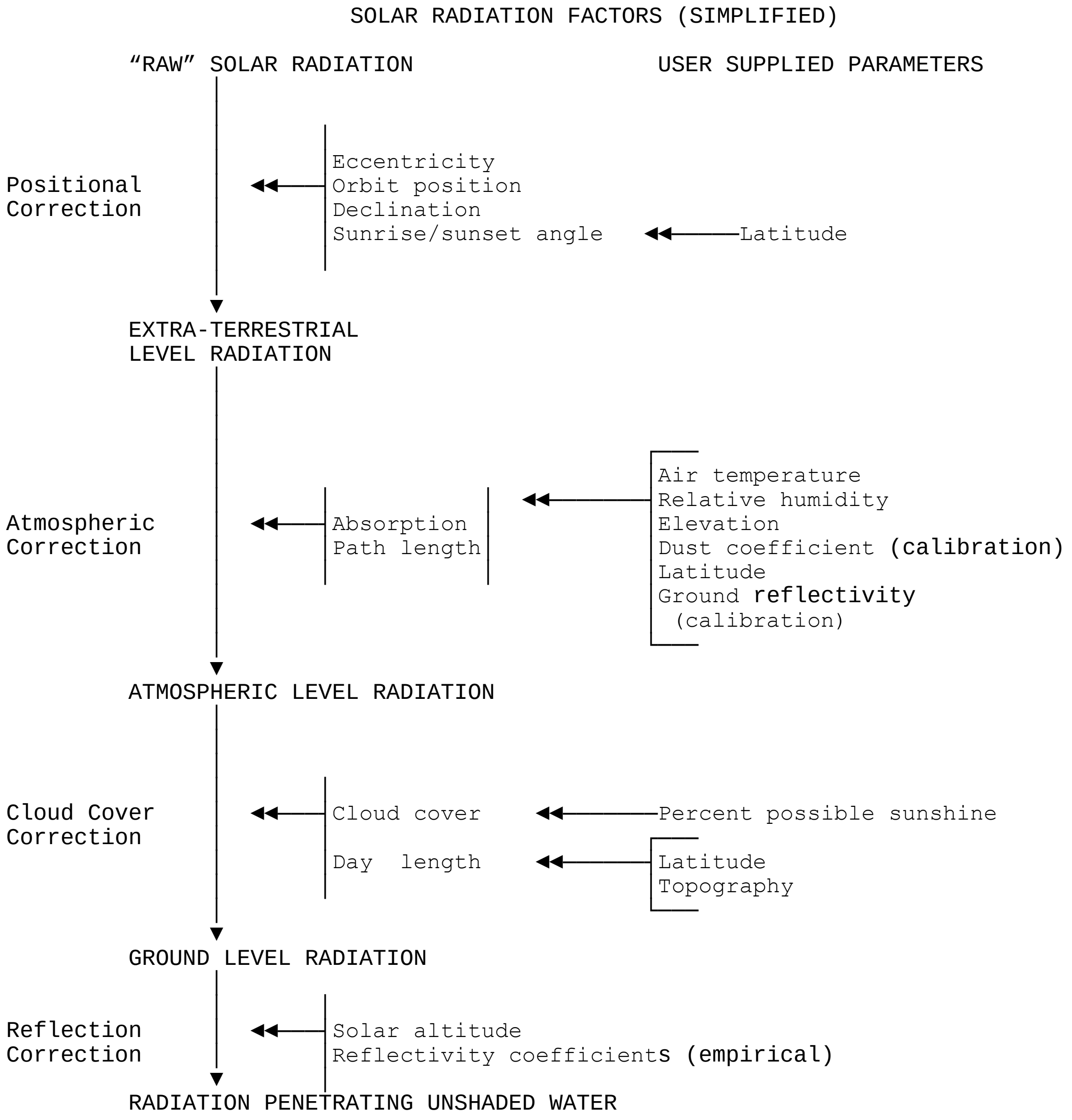


Figure 11.2. SNTEMP's functional schematic for getting radiation from the sun into the water. In this and the following diagrams, user inputs are generally shown on the right hand side of the figure and the processes they influence on the left.

First, we begin with “raw” solar (short wave) radiation. SNTEMP performs a **positional correction** by calculating the position of the sun in the sky relative to the study area’s *latitude* and *time of year*. The position itself is a function of the three million mile eccentricity of the sun in its “apparent orbit"” around the earth (perihelion on December 31st and aphelion on July 2nd), the position on that orbit due to time of year, the orbit’s declination or tilt with respect to the earth’s N-S axis, and the local sunrise-sunset angle given the study area’s longitude on the earth. All of the above factors result in the amount of short wave radiation reaching the earth’s surface if there were no atmosphere, so called extra-terrestrial radiation.

Second, SNTEMP performs an **atmospheric correction** by determining the length and quality of the path that radiation takes through the atmosphere to the study area. Recall for a moment a few things you may have learned about this. Given the earth’s wobble (or the sun’s declination, depending on how you look at it) points along the equator get vertical rays on the equinoxes, September 23 being the autumnal and March 21 the vernal equinox. The tropic of Capricorn and Cancer get vertical rays on Dec 22 and June 12, respectively. Points above or below the tropics (∀23.5°) never get vertical rays. Our atmosphere is 300 miles thick, so the radiation gets attenuated (absorbed and scattered) by that medium. The important factors in addition to latitude are shown in Figure 11.2: *air temperature, relative humidity, elevation* of the study area, *dust* in the air, and *reflectivity* of the surrounding ground cover. This gets us through the atmosphere and to the top of the clouds.

The third step is to get the remaining radiation through the clouds, the **cloud cover correction**. SNTEMP’s primary input here is *percent possible sun*, a measure of the amount of time the sun’s rays are <u>not</u> obscured by the clouds. The model knows how many hours the sun could shine at this latitude and time of year, so it can calculate the amount actually getting through the clouds.

Making it through the clouds is not the last obstacle. The radiation must still make it through any vegetation (which we will discuss in more detail later) on a reach-by-reach basis, and not be reflected off the water’s surface. This **reflection correction** is determined by the altitude of the sun and some empirical relations. In general, about 93% of the direct solar radiation actually penetrates the water to impact heat flux.

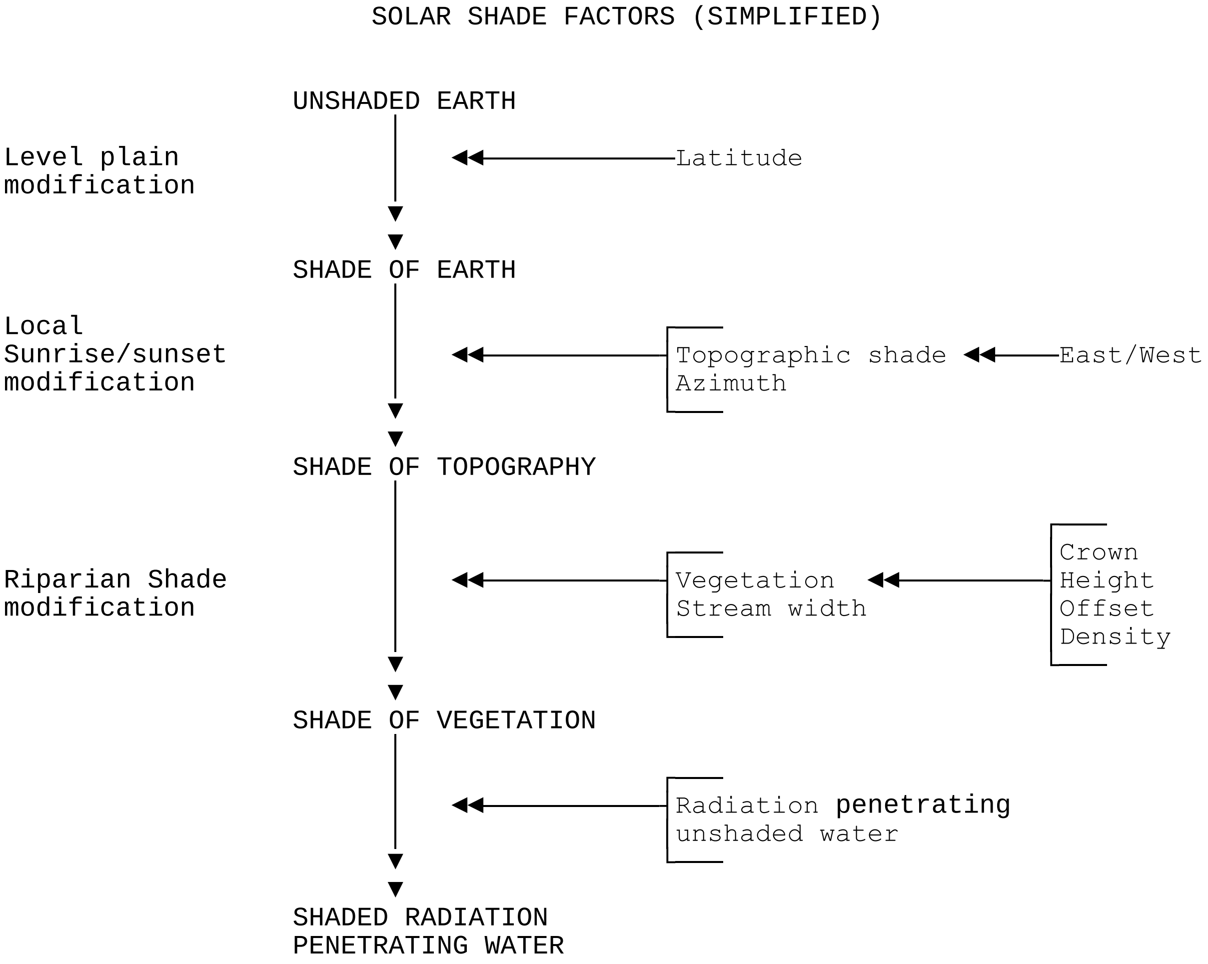


Figure 11.3. Functional schematic for influences of shading on solar radiation.

Just as we took solar radiation through the atmosphere to the water for the study area as a whole, SNTEMP calculates shading for each individual stream reach as influenced by local reach position, topography, and riparian vegetation (Figure 11.3). The large scale process we dealt with earlier essentially considered the sun's rays reaching the earth as if it were a point, but it is actually a sphere and thus generates its own shade in terms of local sunrise and sunset horizons. The first shading calculations assume a perfectly spherical earth and result in the so-called **level plain modification** given the study area's *latitude*.

Next, *local topography* further influences the reach specific **sunrise and sunset**. Eastside and westside topographic measurements combine with the *azimuth* (orientation of the reach with respect to a N-S position) for these calculations. Finally, any intervening vegetation further screens or **shades** the radiation. This is accomplished through trigonometric calculations involving the *diameter* of the trees and their *offset* from the water's edge, the *height* of that vegetation, and the relative *density* (shadow due to filtering and streamside continuity) of the vegetation. Azimuth is determined solely using SNTEMP's convention of always measuring from the N-S axis regardless of direction of flow. The angle is further constrained by convention to be between -90E and +90E. See Figure 11.4.

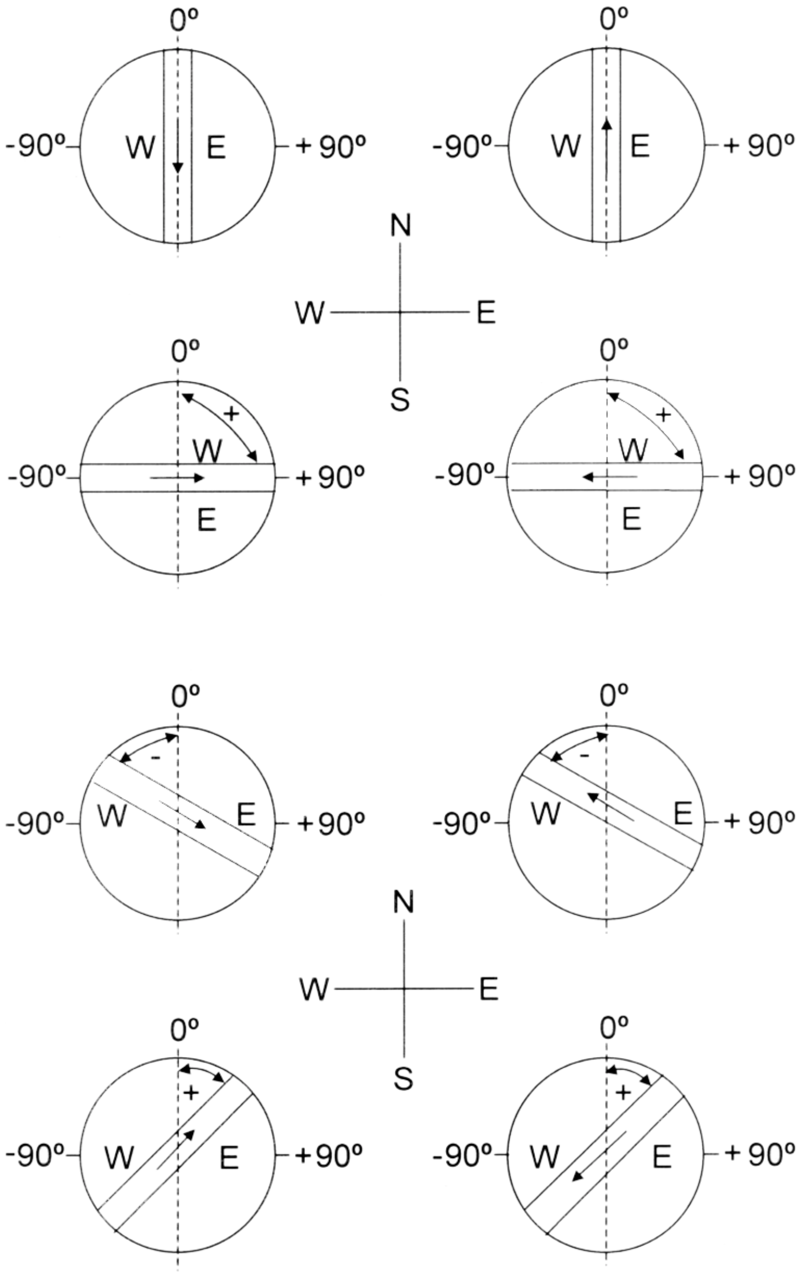


Figure 11.4. Azimuth conventions in SNTEMP and SSTEMP.

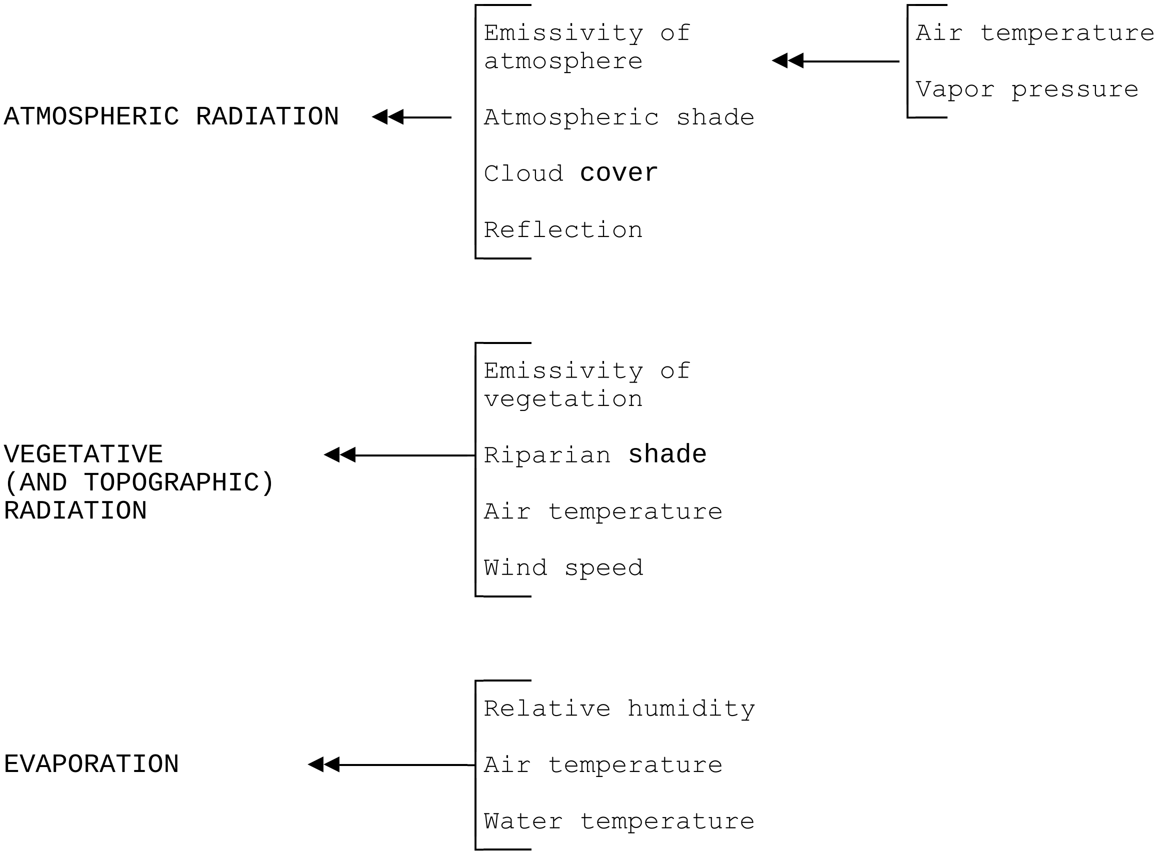


Figure 11.5. Functional schematic #1 for other heat flux components dealing with meteorology.

I'm not going to say much more about the other heat flux components except what is shown in Figures 11.5 and 11.6. **Atmospheric radiation** results from short wave radiation from the sun passing through the atmosphere, some of which is reflected back into space, but some is absorbed and re-radiated, both by the atmosphere and clouds, as long wave radiation. The same thing happens with the local topography and streamside vegetation. *Air temperature* and *wind speed* affect these processes, as do the *emissivity* of the media themselves, which could be considered the efficiency of energy conversion from short to long wave.

Evaporation is controlled by the *air temperature* with respect to that of the water, and the amount of moisture in the air, *relative humidity*. Water that evaporates cools the water that is left behind; water that condenses warms the receiving body. In the heat flux equation, only the sign changes.

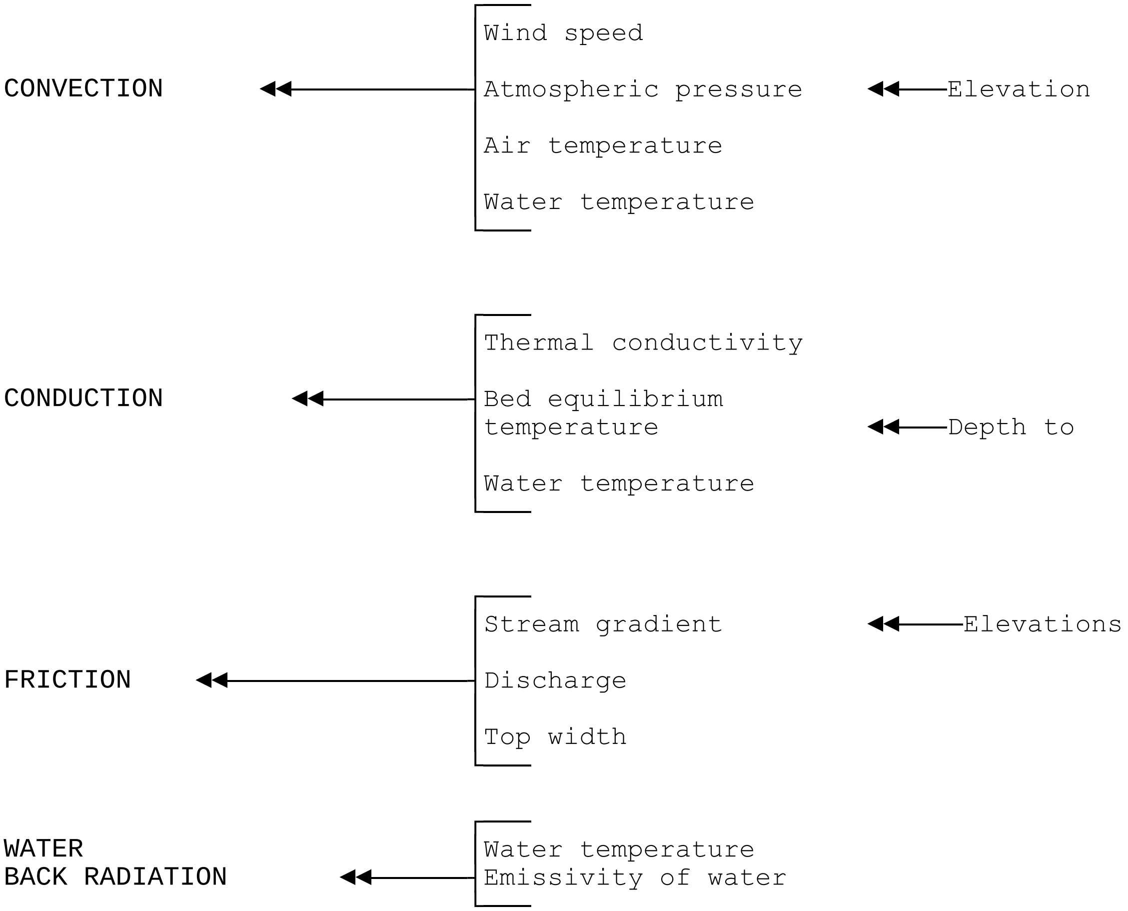


Figure 11.6. Functional schematic #2 for other heat flux components dealing with meteorology.

Convection is that process whereby heat is moved directly from the air into the water (or vice versa), not by radiation, but by direct molecular stimulation. Again, this process is a function of *air temperature* relative to that of the water, and atmospheric pressure that is itself a function of *elevation*. Convection is enhanced by *wind speed*.

Conduction is that process of moving heat to or from the streambed. It is a function of the so-called *thermal gradient*, which is a measure of the insulating capacity of the bed material and the relative temperatures of the water and bed.

Friction is governed by the stream gradient, obviously a function of the *elevations*, but also the *discharge* and the *stream width*. Note that if you have a choice, use bed elevations instead of water surface elevations.

Finally, the water itself gives off radiation much like that from the atmosphere, clouds, vegetation, and topography. This is referred to as **back radiation** and is a function of the *water temperature* and the water's emissivity.

Correction for Elevation

Just when you thought we were through, there are two other important things to learn about SNTEMP and meteorology. First, SNTEMP uses a simplistic way of correcting air temperature for elevation. It employs the so-called **adiabatic** correction of 2°F per 1000 feet. In addition, relative humidity and atmospheric pressure are also corrected for elevation (Figure 11.7). Because the adiabatic correction might not always work well, the model provides the facility to modify this adjustment factor by elevation zone, if you have the data to support it.

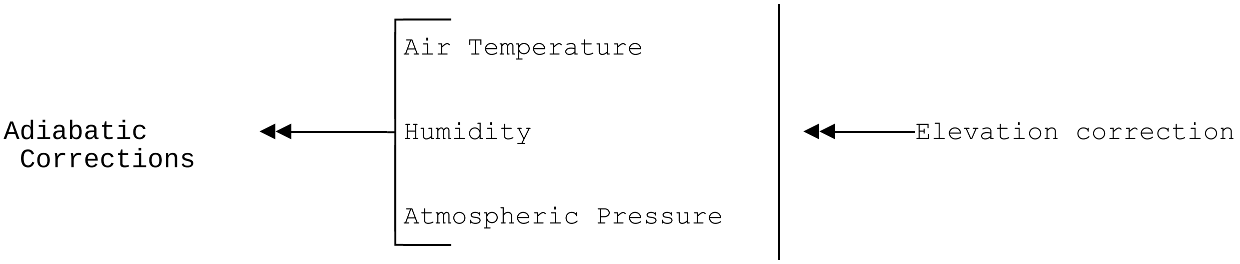


Figure 11.7. Adiabatic correction by elevation.

Second, the maximum daily water temperature estimation is rather a kludge as previously discussed. It is a function of the maximum afternoon air temperature, which is not input to the SNTEMP model. Maybe it will be someday, but until then, the maximum afternoon air temperature is a function of radiation, humidity, percent possible sun, and a set of empirically derived coefficients (Figure 11.8). If you are interested in accurately predicting maximum daily water temperatures, it is recommended that you perform a regression to develop these coefficients for your study area.

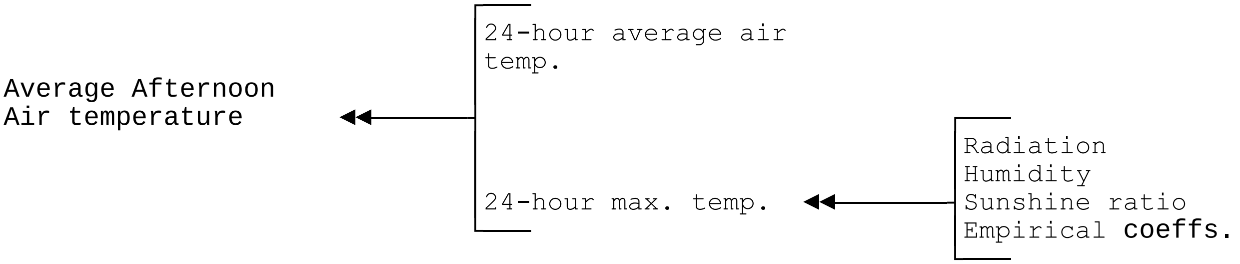


Figure 11.8. Maximum daily air temperature relationships.

Maximum daily water temperatures are also a function of travel time or Manning's n. We have already discussed problems with determining upstream retardance in a dendritic network. Regardless, travel time data are preferable to Manning's n values, if available. Note that daily minimum water temperatures are simply a mirror image around the mean. This may be one of the worst assumptions in the model, if you want to call it that, because diel temperatures are rarely symmetrical, but it is better than nothing.

RULES OF THUMB

> "The Sun, the hearth of affection and life, pours burning love on the delighted earth."
>
> **-** Arthur Rimbaud

Air temperature is the most important meteorological component in controlling mean daily water temperature, typically followed by relative humidity. Solar radiation and wind speed are further down the list, with percent possible sun and ground temperature. However, solar radiation is very important for maximum daily water temperature.

SUGGESTED READINGS FOR TOPIC 11

Bartholow, J. M. 1993. Sensitivity of the U.S. Fish and Wildlife Service's Stream Network Temperature Model. Pages 247-257 *in* Morel-Seytoux, editor, Proceedings of the Thirteenth Annual American Geophysical Union Hydrology Days. Fort Collins, CO.

Mattax, B. L., and T. M. Quigley. 1989. Validation and sensitivity analysis of the stream network temperature model on small watersheds in Northeast Oregon. Pages 391-400 *in* Proceedings of the Symposium on Headwaters Hydrology. W. W. Woessner and D. F. Potts, editors. American Water Resources. Bethesda, MD 20814-2192.

REVIEW QUESTIONS FOR TOPIC 11

Just by looking at the diagrams of meteorological influences on heat flux, how could you tell that air temperature is one of the most important variables?

ANSWERS FOR TOPIC 11

Air temperature occurs more often than any other item on these diagrams. It is influential in almost every process. Which factor shows up with the next greatest frequency?

TOPIC #12: MIXING THE INGREDIENTS:
OVERALL DATA FILE SCHEMA FOR SNTEMP

Time: 0.5 hours
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Understand the full range of input files.
(2) Understand general file building sequence.

Up to now, you have learned about the three major components of the temperature model: stream geometry, hydrology, and meteorology. You should have a good feel for the kinds of input data that are required. What you don't know is how to feed this monster, who, like a young child, is picky at the input trough.

There are actually nine different input files for SNTEMP, further complicated because one (shade) is optional and one (skeleton) is only a useful intermediate product never actually used in the model. As you learn further about the contents of each file and its specific structure, you will grow to appreciate the wisdom of the following figure. Each application is different and you may find that your personal style of assembling data files differs from that shown in Figure 12.1, but it will nonetheless prove instructive to refer to the figure as we proceed.

Subsequent topics cover the individual data file formats in a tedious, field-by-field manner. It will be easy to lose sight of the forest for the trees. Please refer back to the next figure often as it will help guide your learning.

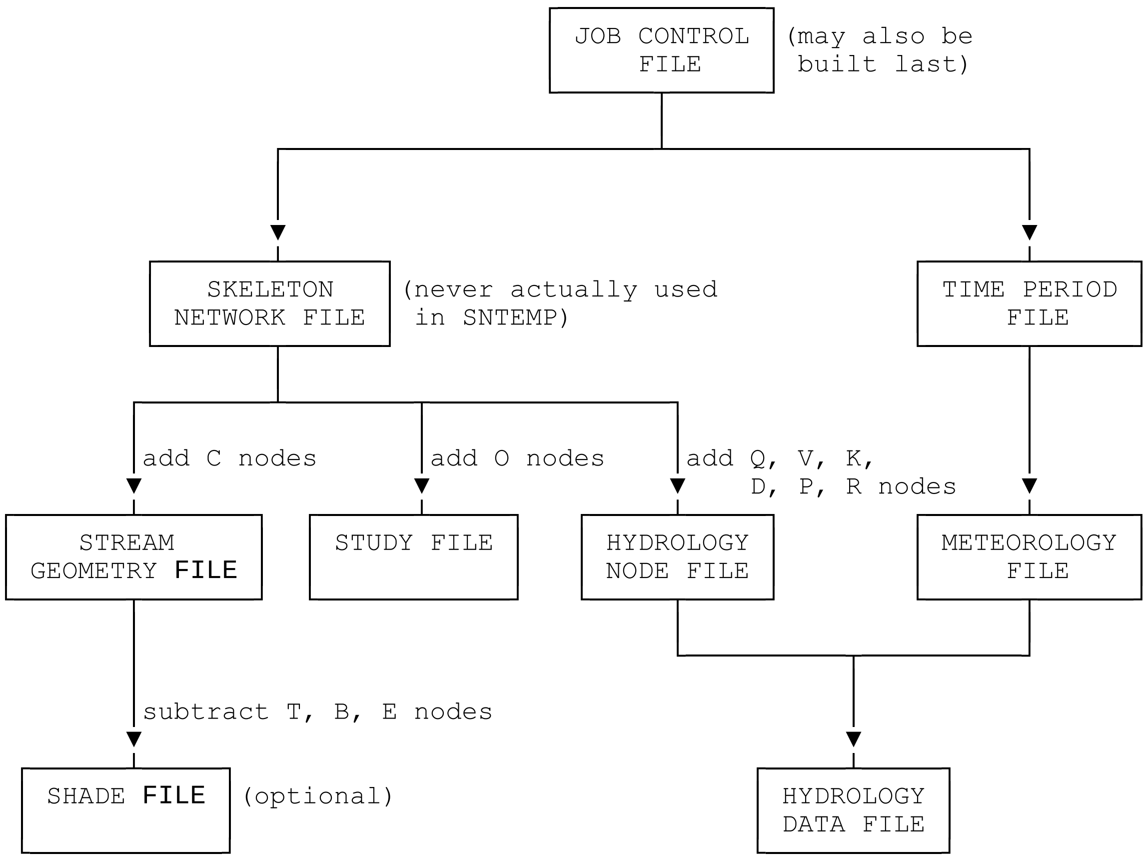


Figure 12.1. Recommended file building sequence. (Adapted from IP#16.)

REVIEW QUESTIONS FOR TOPIC 12

No specific questions.

TOPIC # 13: SPATIALLY ORGANIZED DATA FILES: SKELETON, STUDY, STREAM GEOMETRY, SHADE, AND HYDROLOGY NODE

Time:	1 hour
Format:	Lecture/Reading
Assignment:	Review notebook material
Objectives:	(1) Understand what data goes in which file. (2) Understand specific file formats. (3) Understand any defaults that are available.

Stream identification. SNTEMP has several files that refer to geographic locations, i.e., the nodes. Each node identifier in every file requiring them has a unique identification distinct from every other node. The identification consists of a 16-character **stream name**; an 8-character **node field**, the first character of which is the node type identifier; and an 8-character **distance field** containing the stream distance referenced from a common downstream point (usually the **E** node). Distances always increase upstream. A 47Bcharacter **remarks field** is also allowed. An example node is:

Green River S	661.3	Flaming Gorge Dam

where the stream name is "Green River", node type is "**S**" for Structure, distance is "661.3" kilometers from an arbitrary zero point downstream, and the remarks describe the node location as Flaming Gorge Dam.

Remember, it takes all three fields (stream name, node type, and stream distance) to uniquely identify each node in the network. It is not unreasonable to have two nodes with the same stream name and distance, but different node types. For example a **Q** node and a **C** node may occur at the same location, but to avoid confusion it is best not to. The stream identification must be consistently named on each stream (see example after Table III-5). If your stream changes names, use a hyphenated combination.

The node field (columns 17-24 in all data files requiring identification) is described as:

Column position	Must appear in file	Use
17	All files	Node type -- part of stream identification.
18	Hydrology node	Local output flag -- if this character is a “T”, the corresponding node will appear in all output files regardless of other spatial output flag requests. If this character is an “F”, the corresponding node will not appear in any output files regardless of other spatial output requests. Any other characters, including blanks, default to the global requests found in the job control file.
19	Hydrology node	Number of linkage records -- integer numbers (0-9) used to indicate the number of hydrology linkage records that will immediately follow the current record in the hydrology node file. The linkage records are ignored by the SNTEMP program.
20	Hydrology data	Smooth/fill water temperature regression flag -- default is fill, “S”” is smooth, “F” is fill.
21	Hydrology data	Water temperature regression model option -- default is “1”: 1 - zero lateral heat transport. In general, do not use below an S node. 2 - linear standard 2nd degree multiple regression. 3 - nonlinear complete heat transport; not currently available, will default to option “1”. 4 - self-initialization; for zero discharge H nodes. 5 - flow through, for release temperatures of reservoirs to be set equal to receiving temperatures. 6 - equilibrium release temperatures; for reservoirs where release discharges are skimmed from the surface and are assumed to be near equilibrium water temperature. Beware of negative values during winter.

Column position	Must appear in file	Use
22	Stream geometry	Local shade model flag -- overrides the global shade model flag if nonblank.
23 and 24	Hydrology data	Temperature transfer code.

While it is good practice to have the entire node fields identical for the same node in different files, it is not always necessary. All options pertaining to a specific file must appear in the node field as indicated above.

Skeleton file. Recall from Topic 8 that we defined the so-called skeleton nodes: **H, B, T, J, S**, and **E**. These node descriptors are all grouped in the optional skeleton network file, a file useful for building most of the other required files. The format for that file is given in the following table.

Table III.5. Skeleton network file format.

Record no.	Field	Variable description
1	1 - 80	Title
- - - - - - -	Stream Node Descriptor -	
2	1 - 16	Stream name
2	17 - 24	Node type identifier
2	25 - 32	Distance from the system endpoint (km)
2	33 - 80	Remarks to describe node
3 to end		Repeat stream node descriptor (record 2) for each node

An example of the skeleton node file looks like:

```
SKELETON FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
```

```
GREEN RIVER     S          661.3 FLAMING GORGE DAM
GREEN RIVER     B          556.7 YAMPA RIVER CONFLUENCE
YAMPA RIVER     H          681.5 MAYBELL
YAMPA RIVER     S          652.0 CROSS MOUNTAIN
YAMPA RIVER     B          638.8 LITTLE SNAKE CONFLUENCE
LITTLE SNAKE    H          651.6 LILY GAGE
LITTLE SNAKE    T          638.8 YAMPA CONFLUENCE
YAMPA RIVER     J          638.8 LITTLE SNAKE JUNCTION
YAMPA RIVER     T          556.7 GREEN RIVER CONFLUENCE
GREEN RIVER     J          556.7 YAMPA RIVER JUNCTION
GREEN RIVER     E          399.0 DUSCHESNE RIVER CONFLUENCE
```

Study file. This file contains all the skeleton nodes plus any specific points where temperature output is required by the user. These points may coincide with other studies on the stream system, but are not included in any of the stream features of geometry, hydrology, or shading. An O node is inserted at these points. The format for the study file is given in Table III.7.

Table III.7. Study file format.

Record No.	Field	Variable description
1	1 B 80	Title line
2	1 B 16	Stream name
2	17	Node type
2	18	Local output flag
2	19	Hydrology model linkage flag
2	20 B 21	Regression instructions
2	22	Local shade model linkage flag
2	23 B 24	Unused
2	25 B 32	Distance (km) from system endpoint
2	34 B 80	Remarks describing node
3 |E node		Repeat of record 2 description

An example study file look like:

```
STUDY FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
GREEN RIVER     S          661.3 FLAMING GORGE DAM
GREEN RIVER     B          556.7 YAMPA RIVER CONFLUENCE
YAMPA RIVER   H      681.5 MAYBELL
YAMPA RIVER     S          652.0 CROSS MOUNTAIN
YAMPA RIVER     B          638.8 LITTLE SNAKE CONFLUENCE
LITTLE SNAKE    H          651.6 LILY GAGE
LITTLE SNAKE    T          638.8 YAMPA CONFLUENCE
YAMPA RIVER     J          638.8 LITTLE SNAKE JUNCTION
YAMPA RIVER     T          556.7 GREEN RIVER CONFLUENCE
GREEN RIVER     J          556.7 YAMPA RIVER JUNCTION
GREEN RIVER     O          423.2 OURAY REFUGE STUDY SITE
GREEN RIVER     E          399.0 DUSCHESNE RIVER CONFLUENCE
```

Stream geometry data and file. After **C** nodes have been added to the stream skeleton network, the stream geometry nodes have been defined. The following data have to be supplied at all **H, J, S**, and **C** nodes to complete the resulting stream geometry data: site latitude and elevation, Manning's n-value or travel time, stream width coefficient and exponent, minimum and maximum stream shading, ground temperature, and streambed thermal gradient.

Latitude and elevation should be assigned the values that actually occur at the node location. The other items represent the average conditions between the current and next downstream stream geometry node.

The number of **C** nodes added to the skeleton network is dependent on the overall size of the network, the distance between skeleton nodes, and the uniformity (or homogeneity) of the system. It is recommended that a new **C** node be added whenever significant changes in physical stream geometry or shading occur. The model automatically supplies **M** (meteorological) nodes at every 300-m elevation change, if more than a 300-m difference in elevation exists between user-specified stream geometry nodes.

The stream geometry file is used to record the stream geometry in the system. Each node in the system is defined by three records in the file. One record is a blank line used as a visual separator between nodes. The next line is the node description line, and the third line is the stream geometry data. The format of the stream geometry file is given in Table III.6.

Table III.6. Stream geometry file format.

Record No.	Field	Variable description
1	1 - 80	Title line
2	1 - 80	Blank
3	1 - 16	Stream name
3	17	Node type
3	18	Local output flag
3	19	Hydrology model linkage flag
3	20 - 21	Regression model instructions
3	22	Local shade model linkage
3	23 - 24	Unused
3	25 - 32	Distance (km) from system reference point
3	34 - 80	Remarks describing node (for user's benefit, not used in simulation)
4	1 - 8	Site latitude (radians)
4	9 - 16	Site elevation (m)
4	17 - 24	Manning's n-value for the reach, not required for B, T, or E nodes
4	25 - 32	Stream width coefficient for the reach (m)
4	33 - 40	Stream width exponent

Table 6. (continued)

Record No.	Field	Variable description
4	41 - 48	Minimum stream shading (decimal), required only if you are not using shade file
4	49 - 56	Maximum stream shading (decimal), required only if you are not using shade file
4	57 - 64	Ground temperature (°C), defaults to mean annual air temperature
4	65 - 72	Streambed thermal gradient (J/m^2/sec/C), default + 1.65
4	73 - 80	Blank
5, 6, and 7 |E node		Repeat information similar to records 2-4 for next geometry node

The stream width may vary as a power function of the flow, i.e.:

$$\text{width} = (\text{width coefficient}) * \text{flow}^{(\text{width exponent})}$$

If a constant width is desired, the width exponent can be set to zero and the width coefficient set to the desired width.

An example stream geometry file is shown below. Why do you think **T, B**, and **E** nodes are different?

```
STREAM GEOMETRY FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET

GREEN RIVER     S          661.3 FLAMING GORGE DAM
  .71413   1707.    .030   60.96    0.00  0.0001  0.0564

GREEN RIVER     C          617.9 LITTLE BROWN PARK
  .71326   1636.    .030   91.44    0.00  0.0022  0.0089

GREEN RIVER     C          580.8 LADORE CANYON
  .71035   1625.    .030   45.72    0.00  0.0962  0.2014

GREEN RIVER     C          566.4 HELLS HALF MILE
  .71035   1565.    .030   60.96    0.00  0.1591  0.3004

GREEN RIVER     B          556.7 YAMPA RIVER CONFLUENCE
  .70744   1544.

YAMPA RIVER     H          681.5 MAYBELL
  .70686   1805.    .030   76.20    0.00  0.0000  0.0004

YAMPA RIVER     S          652.0 CROSS MOUNTAIN
  .70686   1805.    .030   76.20    0.00  0.0000  0.0004

YAMPA RIVER     B          638.8 LITTLE SNAKE CONFLUENCE
  .70715   1709.

LITTLE SNAKE    H          651.6 LILY GAGE
  .70744   1720.    .030   38.10    0.00  0.0019  0.0066

LITTLE SNAKE    T          638.8 YAMPA CONFLUENCE
  .70715   1709.

YAMPA RIVER     J          638.8 LITTLE SNAKE JUNCTION
  .70715   1709.    .030   45.72    0.00  0.0001  0.0019

YAMPA RIVER     C          627.5 LILY PARK
  .70744   1702.    .030   45.72    0.00  0.0000  0.0498

YAMPA RIVER     C          585.7 HARDING HOLE
  .70744   1575.    .030   45.72    0.00  0.0000  0.7673

YAMPA RIVER     T          556.7 GREEN RIVER CONFLUENCE
  .70744   1544.

GREEN RIVER     J          556.7 YAMPA RIVER JUNCTION
  .70744   1544.    .030   76.20    0.00  0.0000  0.6363

GREEN RIVER     C          537.4 ISLAND PARK
  .70686   1509.    .030  121.92    0.00  0.0036  0.0141

GREEN RIVER     C          526.1 RAINBOW PARK
  .70686   1503.    .030   60.96    0.00  0.0036  0.0141

GREEN RIVER     C          510.1 SPLIT MOUNTAIN
  .70628   1454.    .030   76.20    0.00  0.0544  0.1811

GREEN RIVER     C          502.0 FLATLAND BELOW SPLIT MOUNTAIN
  .70570   1446.    .030   91.44    0.00  0.0004  0.0018

GREEN RIVER     E          399.0 DUSCHESNE RIVER CONFLUENCE
  .69988   1415.
```

Shade data and file. The shade file contains the information required to run the shade model concurrently with the temperature model. The shade values produced by this model are used in computing the effect of riparian and topographic shade on water temperatures. This file is optional and is only required if the shade model is selected by the user during a run of the temperature model. The node points in this file are identical to the node points in the stream geometry file that actually required stream geometry data; i.e., **B, T**, and **E** nodes are not included. The shade file format is described in Table III.10.

Table III. 10. Shade file format.

Record No.	Field	Variable description
1	1 - 80	Title line
2	1 - 80	Blank
3	1 - 16	Stream name
3	17	Node type
3	18	Local output flag
3	19	Hydrology model linkage flag
3	20 - 21	Regression model instructions
3	22	Local shade model linkage flag
3	23 - 24	Unused
3	25 B 32	Distance from system endpoint (km)
3	34 - 80	Remarks describing node
4	1 - 8	Site latitude (radians)
4	9 - 16	Stream reach azimuth (radians)
4	17 - 24	Stream width (m)

Table III.10 (concluded).

Record No.	Field	Variable description
4	25 - 80	Blank
5	1 - 8	Eastside topographic altitude (radians)
5	9 - 16	Eastside vegetation crown measurement (m)
5 1	7 - 24	Eastside vegetation height (m)
5	25 - 32	Eastside vegetation offset (m)
5	33 - 40	Eastside vegetation density (conifer); minimum density for deciduous trees
5	41 - 48	Eastside maximum density for deciduous trees; blank for conifers
6	1 - 80	Repeat of record 5 for westside parameters
For the remaining nodes		Repeat records 2 - 6

A portion of an example shade data file looks like:

```
SHADE FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET

GREEN RIVER     S          661.3 FLAMING GORGE DAM
   .7141 -1.0472   60.96
   .2443    0.00    0.00    0.00  0.0000
   .2443    0.00    0.00    0.00  0.0000

GREEN RIVER     C          617.9 LITTLE BROWN PARK
   .7133  -.5236   91.44
   .0844    0.00    0.00    0.00  0.0000
   .0844    0.00    0.00    0.00  0.0000

GREEN RIVER     C          580.8 LADORE CANYON
   .7104   .1745   45.72
   .4363    0.00    0.00    0.00  0.0000
   .4189    0.00    0.00    0.00  0.0000
```

Hydrology node file. This file contains all skeleton nodes plus all nodes where additional hydrology data is required (**D, K, P, Q, R**, and **V** nodes). The node identifier field in this file carries the instruction codes for the regression model. The records in this file can contain information used to link the instream temperature model with a hydrology model. Up to nine linking records can follow each node record as specified in field 19. The format of the linking records may vary depending on the type of linkage being performed. If the temperature model is to be used in conjunction with a hydrology model, the linkage documentation must be checked prior to building the hydrology node file. The format of the hydrology node file is given in Table III.8.

Table III. 8. Hydrology node file format.

Record No.	Field	Variable description
1	1 - 80	Title line
2	1 - 16	Stream name
2	17	Node type
2	18	Local output flag
2	19	Number of records that follow with hydrology linkage instructions (digit)
2	20 - 21	Regression model instructions
2	22	Local shade model linkage flag
2	23 - 24	Unused
2	25 - 32	Distance from system endpoint (km)
2	34 - 80	Remarks describing node
3 |E node		Repeat of record 2

The format for hydrology linkage instructions, if any, that would follow the associated hydrology node record (see record 2, column 19 above) is ignored by this program. These records are for the user's convenience to link with other hydrology computer programs.

An example hydrology node file is shown below. Note the four optional linkage records.

```
HYDROLOGY NODE FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
GREEN RIVER     S 1S2      661.3 FLAMING GORGE DAM
        09234500
GREEN RIVER     B          556.7 YAMPA RIVER CONFLUENCE
YAMPA RIVER     H 1        681.5 MAYBELL
        09251000
YAMPA RIVER     S   5      652.0 CROSS MOUNTAIN
YAMPA RIVER     B          638.8 LITTLE SNAKE CONFLUENCE
LITTLE SNAKE    H 1        651.6 LILY GAGE
        09260000
LITTLE SNAKE    T          638.8 YAMPA CONFLUENCE
YAMPA RIVER     J          638.8 LITTLE SNAKE JUNCTION
YAMPA RIVER     T          556.7 GREEN RIVER CONFLUENCE
GREEN RIVER     J          556.7 YAMPA RIVER JUNCTION
GREEN RIVER     V 1S       485.9 JENSEN GAGE
        09261000
GREEN RIVER     E          399.0 DUSCHESNE RIVER CONFLUENCE
```

RULES OF THUMB

> "Men who wish to know about the world must learn about it in its particular details."
>
> - Heraclitus

I usually skip the skeleton file and go straight to the study file. Most often they are really the same thing since study nodes (**O**) are actually rarely used.

NOTE: To be safe, always separate nodes by 1/10 kilometer. It makes your setup clear to you and your information consumers, and it avoids ambiguities for the SNTEMP model to digest.

SUGGESTED READINGS FOR TOPIC 13

Theurer, F. D., K. A. Voos, and W. J. Miller. 1984. Part II in Instream Water Temperature Model. Instream Flow Information Paper 16. U.S. Fish and Wildlife Service. FWS/OBSB84/15. v.p.

REVIEW QUESTIONS FOR TOPIC 13

No specific questions.

TOPIC #14: TEMPORALLY ORGANIZED DATA FILES: TIME PERIOD, METEOROLOGY, HYDROLOGY DATA

Time:	1 hour
Format:	Lecture/Reading
Assignment:	Review notebook material
Objectives:	(1) Understand what data goes in which file. (2) Understand specific file formats. (3) Understand any defaults that are available.

Just as the skeleton and other “node” files shared a common format, the temporal file family shares a similar lineage, though each is in its own way more distinct from one another. The *time period file* is the simplest, containing values used repetitively year in and year out. The *meteorology file* contains annually varying values that act globally throughout the study area. The *hydrology data file* is sort of a hybrid. It contains annually varying values for the entire spatial network of nodes.

Note that when I say annually, we could easily be dealing with only a portion of a year. It is not uncommon, for example, to run SNTEMP only from May through October, that period of the year when elevated temperatures are common and when diversions are most in demand.

Time Period Data and File

Time periods are groups of continuous days within each year that occur on a repeating cycle, e.g., months, weeks, or days. Values for the following variables are required for each time step to be simulated: time period name, first and last Julian day (see Reference section for a handy list of Julian days) of the time period, dust coefficient and ground reflectivity, air temperature calibration constant and coefficient, wind speed calibration constant and coefficient.

The time period file is used to define the time periods to be simulated during each year and to assign values to variables that vary only by time period and not yearly. The format of this file is presented in Table III.3.

Table III.3. Time period file format.

Record no.	Field	Variable description
1	1 - 80	Title line
2	1 - 8	Time period name
2	9 - 16	First day of simulation period (Julian)
2	17 - 24	Last day of simulation period (Julian)
2	25 - 32	Number of points in time period average (usually 1)
2	33 - 40	Dust coefficient for simulation period, see page II-13
2	41 - 48	Ground reflectivity for simulation period, see page II-14
- - - - - - - - - - - - - - - Calibration Factors by Time Period -		
2	49 - 56	Air temperature calibration constant (°C)
2	57 - 64	Air temperature calibration coefficient
2	65 - 72	Wind speed calibration constant
2	73 - 80	Wind speed calibration coefficient
3 |total time periods		Repeat calibration factors (record 2) for each respective time period

An example of the time period file is:

```
TIME PERIOD FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET

   OCT    274.    304.      2.  .16070  .33460   0.000  0.0000   0.000  0.0000
   NOV    305.    334.      2.  .17910  .40450   0.000  0.0000   0.000  0.0000
   DEC    335.    365.      2.  .19220  .25030   0.000  0.0000   0.000  0.0000
   JAN      1.     31.      2.  .19890  .18990   0.000  0.0000   0.000  0.0000
   FEB     32.     59.      2.  .19890  .25390   0.000  0.0000   0.000  0.0000
 MARCH     60.     90.      2.  .19250  .37070   0.000  0.0000   0.000  0.0000
 APRIL     91.    120.      2.  .17970  .29410   0.000  0.0000   0.000  0.0000
   MAY    121.    151.      2.  .16130  .40250   0.000  0.0000   0.000  0.0000
  JUNE    152.    181.      2.  .13890  .28120   0.000  0.0000   0.000  0.0000
  JULY    182.    212.      2.  .11370  .16140   0.000  0.0000   0.000  0.0000
AUGUST    213.    243.      2.  .11280  .12690   0.000  0.0000   0.000  0.0000
  SEPT    244.    273.      2.  .13810  .22690   0.000  0.0000   0.000  0.0000
```

The time period calibration factors are used in the computer program to modify only the two indicated meteorological parameters, and does so for each associated time period according to the general form:

$$y_u = a_o + a_1 y_o$$

where y_u = the modified time period meteorological parameter

y_o = the original input (or as modified previously by the global calibration factor) time period meteorological parameter

a_o = calibration constant factor for the indicated timer period

a_1 = calibration coefficient factor for the indicated time period

Annual (referred to as global in IP#16) calibrations are made first and any subsequent time period by time period calibrations are made afterwards. Blanks or zeros in both factor fields (constant and coefficient) for each meteorological parameter means that there will be no time period calibration for the indicated parameter and time period. If either field is non-blank, a an adjustment will be made for the appropriate parameter and time period according to the general form shown above.

Meteorology Data and File

The instream water temperature model uses only one set of meteorological data. Therefore data should be obtained from one meteorological station that is representative of the study area. Alternatively, a single set may be synthesized using data from several stations.

Three time constant parameters that define the conditions of the meteorological data station are required: latitude of the station, elevation of the station, average annual air temperature. Values for the following variables are supplied for all years and time periods simulated: air temperature, wind speed, humidity, and sunshine ratio. Optional input includes measured solar radiation at ground level. The first four variables are required for all years and time periods. Values for solar radiation are optional and, when supplied, only the values entered for the last year are used and they are assumed to apply for all years.

The first record of the meteorology file is the title. The second record defines the meteorological station constants: (1) latitude; (2) elevation; and (3) mean annual air temperature. The remaining records in the file contain year and time period names, air temperature, wind speed, relative humidity, sunshine ratio, and, as optional data, any solar radiation measured at ground level for each time period of each year to be simulated. The format of the file is defined in Table III.4.

Table III.4. Meteorology file format.

Record no.	Field	Variable description
1	1 - 80	Title line
- - - - - - - - - - - - - - - - - - - Meteorological Station Constants -		
2	1 - 16	Blank
2	17 - 24	Latitude (radians)
2	25 - 32	Elevation (m)
2	33 - 40	Average annual air temperature (°C)
2	41 - 80	Remarks to describe station
- - - - - - - - - - - - - - - - - Meteorological Time Period Data -		
3	1 - 8	Year (only needed for first time period of the year)
3	9 - 16	Time period name
3	17 - 24	Mean air temperature for the time period (°C)
3	25 - 32	Mean wind speed for the time period (m/sec)
3	33 - 40	Relative humidity for the time period (decimal)
3	41 - 48	Percent sunshine for the time period (decimal)
3	49 - 56	Observed solar radiation at ground level ($J/m^2/sec$) (optional)
3	57 - 80	Blank
4 |total time periods		Repeat meteorological data (record 3) for each year and time period

An example of the meteorology file is shown below:

```
METEOROLOGY FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
                 .682715   1475.    11.5
 1962-63     OCT   16.28    2.41   .3950   .7500
             NOV    6.67    2.41   .5400   .7100
             DEC   -2.72    1.74   .5950   .6300
             JAN   -3.61    2.15   .5780   .6900
             FEB   -1.39    2.77   .4250   .8300
           MARCH    2.78    2.82   .4630   .6000
           APRIL   10.17    3.67   .4550   .5700
             MAY   16.83    4.02   .3000   .7300
            JUNE   21.22    4.20   .2850   .7300
            JULY   27.39    4.43   .2950   .8000
          AUGUST   23.39    3.98   .3800   .7700
            SEPT   19.22    3.89   .3800   .8500
 1981-82     OCT   10.39    3.93   .6050   .6100
             NOV    5.33    3.40   .6225   .6400
             DEC   -0.39    2.91   .7325   .5100
             JAN   -3.33    3.40   .7025   .5700
             FEB    1.50    3.04   .6425   .6400
           MARCH    7.78    4.34   .5300   .6500
           APRIL   10.72    5.01   .3450   .8300
             MAY   16.33    4.52   .4150   .7800
            JUNE   22.33    5.19   .2775   .8800
            JULY   26.11    4.16   .3275   .9300
          AUGUST   25.67    3.89   .4675   .7800
            SEPT   19.72    4.20   .5400   .6400
  NORMAL     OCT   12.72    3.53   .4450   .7300   176.7
             NOV  4.33      2.95   .5750   .6300   120.6
             DEC  -1.39     2.64   .6800   .6000    86.1
             JAN  -3.00     2.50   .7075   .5900   103.9
             FEB    .89     2.95   .5800   .6400   147.0
           MARCH  5.11      3.75   .4850   .6300   204.1
           APRIL  10.94     4.29   .3975   .6800   260.9
             MAY  16.78     4.29   .3700   .7100   312.6
            JUNE  21.83     4.38   .2950   .8000   342.4
            JULY  25.94     4.16   .3300   .7800   324.5
          AUGUST  24.11     4.02   .3550   .7600   286.6
            SEPT  19.56     4.02   .3750   .7900   241.0
```

Hydrology Data and File

Flow data (cms) should be supplied for all simulation periods at all nodes in the skeleton network and at all hydrology (**Q, D, P, R, V**, and **K**) nodes. The flows at **K, Q**, and **V** nodes represent the flow within the channel at the respective node. Flows provided at **P** and **R** nodes represent the addition to the flow in the channel by the P or R node, respectively. The flow at a **D** node, always a positive number, is the amount of flow being diverted from the channel at this node.

Water temperatures should be supplied for all years and time periods at all headwaters (**H**) with a nonzero discharge. Point (**P**) load discharge temperatures should be supplied for all years and time periods at point loads. Lateral discharge temperatures must be supplied at any point where the lateral inflow is not at local mean annual air temperature. If a validation and/or calibration is to be performed, water temperatures should be supplied at all **V** nodes. If an occasional value for the historical water temperature is missing, the field should be left blank so that the regression model will supply an estimated temperature for that period.

The temperature of water released from structures (**S**:reservoirs) must be provided (or options selected) for all simulation periods. Upstream inflow discharges to reservoirs must be provided for computation of lateral accretions above the reservoir.

The hydrology data file is a copy of the hydrology node file with discharge and temperature information added. Hydrology data are added for all years and time periods at one node before moving to the next node (time major, space minor order).

An option has been added to the SNTEMP's TRNSPT program to allow temperatures to be transferred from a Diversion (**D**) node to a downstream Headwater (**H**) or Point load (**P**) node. The option is designed to handle cases where water is transferred by a pipe or canal to a downstream location, typically a power system bypass (see Figure 14.1). Hydropower projects with power canals, pipelines, or tunnels (that divert water around a natural stream reach) therefore can be handily simulated. (Note that this implementation may also be used to handle systems with split/braided channels.) The temperatures simulated at the **D** node are used as given (observed) temperatures for the downstream node. No heat flux takes place between the **D** node and the target downstream node.

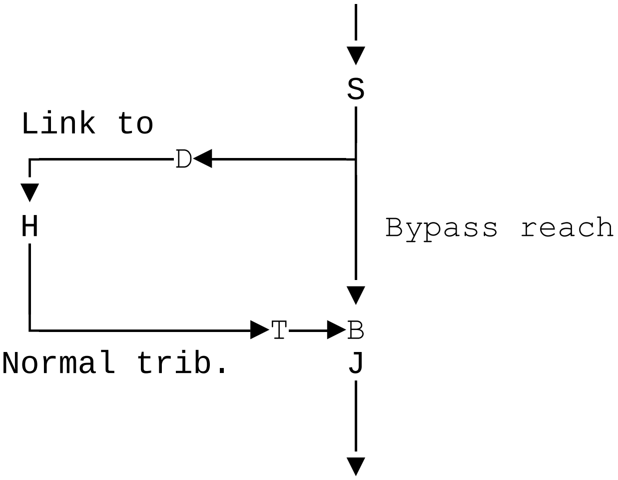


Figure 14.1. Example of diversion temperature transfer.

A temperature transfer is indicated by non-blank characters in columns 23-24 of the node line in the hydrology data file. Only **D, P**, or **H** nodes can have legal transfer codes. A transfer code must appear on a **D** node first, and can then be referred to by any subsequent **H** or **P** node downstream. The TRNSPT program keeps a list of transfer codes from **D** nodes. When an **H** or **P** node with a transfer code occurs, the program searches for the matching transfer code from the upstream **D** node. Thus, the transfer codes must occur in pairs in the hydrology data file. Up to 10 transfer pairs are allowed on a data set.

Water temperatures may be passed to an **H** node if the canal acts like a tributary with heat flux downstream, or to a **P** node if there is a tunnel or pipeline that gets no heat flux. **R** nodes are not allowed because of the optional ways of supplying water temperatures for an **R** node. **S** nodes are also not allowed as targets for similar reasons.

You must supply water temperatures for all time periods for all **H** or **P** nodes that are targets for upstream "diversion", though they may be dummy values. The target node(s) must not use regression options (i.e., columns 20-21 must be blank).

No error will occur if a **D** node transfer code does not match any downstream transfer code, or if more than one downstream transfer code matches the same **D** node transfer code -- the first matching code will be used. Warnings will occur if a downstream transfer code has no match, or if a transfer code is found on a node type other than **D, P**, or **H**. Errors may also occur if the **H** or **P** node receiving the temperatures has missing temperature data or has regression options set. These messages will be provided by the REGTWO program. (NOTE: The TDATCHK program also checks for matching transfer codes and correct node types. However, it is possible to screw up royally, so please be careful.)

The format for the hydrology data file is given in Table III.9.

Table III. 9. Hydrology data file format.

Record No.	Field	Variable description
1	1 - 80	Title line
2	1 - 80	Blank
3	1 - 16	Stream name
3	17	Node type
3	18	Local output flag
3	19	Unused
3	20 - 21	Regression model instructions
3	22	Local shade model linkage flag
3	23 - 24	Temperature transfer code (see above)
3	25 - 32	Distance from system endpoint (km)
3	34 - 80	Remarks describing node
4	1 - 8	Year (first time period of the year only)
4	9 - 16	Time period name
4	17 - 24	Discharge for the time period (cms)
4	25 - 32	Water temperature of the discharge (°C); see below for **R** nodes
4	33 - 40	Lateral inflow temperature (°C), defaults to mean annual air temperature
4	41 - 48	Upstream inflow at a reservoir (**S** node), need not be supplied at a "flow through" reservoir
5 until maximum years and time periods		Repeat record 4 format for each year and time period

Note: for each node in the hydrology node file, repeat records 2 through the maximum number of years and time periods.

Return (**R**) flow water temperatures are controlled by the user. If the water temperature input field is blank, equilibrium water temperature is assumed. This simulates an overland flow condition. If the field is nonblank and nonzero, the value is assumed to be a ratio of lateral inflow and equilibrium water temperatures. If nonblank and negative, the absolute value is assumed to be the return flow water temperature. This last option is therefore similar to a **P** node.

An example of a portion of a hydrology data file is shown below:

```
HYDROLOGY DATA FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET

GREEN RIVER     S 1S2      661.3 FLAMING GORGE DAM
 1962-63     OCT  22.010    8.82
             NOV   2.550    4.27
             DEC   7.600    0.59
             JAN  10.400    2.32
             FEB  13.240    1.59
           MARCH   2.990    1.93
           APRIL   3.790    2.41
             MAY   3.690    4.03
            JUNE   3.540    5.28
            JULY   2.950    6.33
          AUGUST   2.870    6.95
            SEPT   3.190    5.48
 1981-82     OCT  40.910   10.62
             NOV  35.820    7.53
             DEC  36.160    4.59
             JAN  38.090    4.43
             FEB  75.070    4.00
           MARCH  43.150    4.50
           APRIL  66.260    4.91
             MAY  44.180    8.20
            JUNE  40.560   12.02
            JULY  40.130   13.00
          AUGUST  50.300   13.00
            SEPT  65.610   12.95
  NORMAL     OCT  51.570    9.20
             NOV  52.940    8.37
             DEC  57.040    6.86
             JAN  53.400    4.71
             FEB  54.800    3.83
           MARCH  47.660    3.86
           APRIL  54.130    4.96
             MAY  58.660    6.18
            JUNE  66.350    7.88
            JULY  60.380    9.29
          AUGUST  56.840    9.85
            SEPT  51.930    9.83

GREEN RIVER     B          556.7 YAMPA RIVER CONFLUENCE
 1962-63     OCT  22.324
             NOV   4.087
             DEC   7.453
             JAN  11.540
```

```
             FEB  14.707
           MARCH   4.357
           APRIL   4.632
             MAY   2.136
            JUNE   4.305
            JULY   3.966
          AUGUST   3.438
            SEPT   4.487
 1981-82     OCT  43.356
             NOV  37.528
             DEC  36.625
             JAN  40.319
             FEB  80.517
           MARCH  45.162
           APRIL  63.740
             MAY  37.419
            JUNE  29.241
            JULY  42.723
          AUGUST  52.756
            SEPT  68.461
  NORMAL     OCT  52.736
             NOV  54.123
             DEC  58.009
             JAN  55.017
             FEB  57.614
           MARCH  50.531
           APRIL  53.956
             MAY  56.518
            JUNE  67.830
            JULY  62.556
          AUGUST  58.123
            SEPT  52.749

YAMPA RIVER     H 1        681.5 MAYBELL
 1962-63     OCT   8.140   11.64
             NOV   8.160    5.46
             DEC   6.130    1.75
             JAN   6.030    0.82
             FEB  11.070    1.52
           MARCH  13.210    5.36
           APRIL  37.490    9.78
             MAY 115.570   13.15
            JUNE  70.100   16.76
            JULY   7.630   23.75
          AUGUST   6.100   22.51
            SEPT   5.640   18.69
 1981-82     OCT   8.890
             NOV   7.600
             DEC   8.230
             JAN   8.310
             FEB  10.810
           MARCH  20.600
           APRIL  70.320
             MAY 194.440
            JUNE 204.520
            JULY  82.000
          AUGUST  16.880
```

```
            SEPT  10.220
  NORMAL     OCT   9.710   11.90
             NOV   9.100    4.52
             DEC   7.390    1.45
             JAN   7.180    1.34
             FEB   8.940    1.54
           MARCH  16.490    2.94
           APRIL  68.540    7.17
             MAY 163.170   11.18
            JUNE 152.640   14.76
            JULY  41.380   20.33
          AUGUST   9.690   21.51
            SEPT   5.980   18.30
...

GREEN RIVER     E          399.0 DUSCHESNE RIVER CONFLUENCE
 1962-63     OCT  32.274
             NOV  18.438
             DEC  14.960
             JAN  21.140
             FEB  32.351
           MARCH  26.928
           APRIL  57.470
             MAY 155.950
            JUNE  99.310
            JULY  14.465
          AUGUST  12.830
            SEPT  15.420
 1981-82     OCT  67.695
             NOV  54.222
             DEC  50.986
             JAN  56.690
             FEB 105.840
           MARCH  80.489
           APRIL 152.640
             MAY 309.170
            JUNE 297.480
            JULY 161.573
          AUGUST  80.186
            SEPT  89.323
  NORMAL     OCT  68.371
             NOV  69.381
             DEC  70.080
             JAN  68.010
             FEB  76.683
           MARCH  85.054
           APRIL 148.640
             MAY 284.750
            JUNE 282.389
            JULY 120.742
          AUGUST  71.862
            SEPT  61.740
```

RULES OF THUMB

Ground reflectivity trivia. It has been estimated that Los Angeles would save $90 million if they replaced all their black asphalt with a lighter colored, more reflective, road surface. Fresh black asphalt was tested to absorb 95 percent of solar radiation. Aged asphalt, which is gray rather than black, was found to absorb 90 percent, and experimental white asphalt soaked up just 50 percent. The three side-by-side pavements were measured as: new pavement, 123°F; faded asphalt, 115°F; and the white surface, 90°F.

SUGGESTED READINGS FOR TOPIC 14

Theurer, F. D., K. A. Voos, and W. J. Miller. 1984. Part II in Instream Water Temperature Model. Instream Flow Information Paper 16. U.S. Fish and Wildlife Service. FWS/OBSB84/15. v.p.

REVIEW QUESTIONS FOR TOPIC 14

No specific questions, but it would be wise to compare the format specifications with the examples. Note that not all options are illustrated in the above examples.

TOPIC #15: COVERING THE BASES: DATA FILE UNDERSTANDING

Time:	1-2 hours
Format:	Homework
Assignment:	(1) Review listings of input data files. (2) Cross-check data elements with file formats to know what every element means and where it goes. (3) Be prepared to ask questions tomorrow.
Objectives:	Familiarization with data, file content, and file formats.

Some people find the following table useful in seeing the big picture. Some don't. The idea is that it shows what data or information is required for each node type, breaking it down by what is constant (applies all the time), what is annually recurring, and what varies for each time step of the model.

DATA REQUIREMENTS FOR THE TEMPERATURE MODEL

SPACE	TIME		
Nodes	Constant	Annually recurring, but seasonal variation	Variable for each time step
Skeleton (**H**, **B**[*], **T**[*], **J**, **S**, **E**[*])	Name[#] Type[#] Distance[#] Remarks[#] Latitude Elevation Manning's n Width Width exponent Min shade value[S] Max shade values[S] Ground temperature[D] Thermal gradient[D] Reach azimuth (for shade model only)	None	Discharge Disc. temp. Lateral temp.[D] Upstream inflow at **S** nodes
Hydrology (**D**[+], **K**, **P**, **Q**, **R**, **V**)	Core (#) attributes only	None	Ditto skeleton
Geometry (**C**)	Ditto skeleton	None	None
Study (**O**)	Core (#) attributes only	None	None
Basin-wide	Latitude Elevation Mean annual air temperature	Julian days Dust coefficient Ground reflectivity	Air temp.[C] Wind speed[C] Sunshine ratio[C] Obs. solar rad.[CD]

NOTES:
[*] Only latitude and elevation required
[+] No temperature necessary
[#] Core attributes necessary at all nodes
[C] Calibration variables
[D] Defaults available
[S] May be calculated from stand alone shade model

TOPIC #16: QUESTIONS FROM DAY 2

Time: 0.25 hours
Format: Discussion
Assignment: Be prepared to ask for clarification.
Objectives: Clarity, perspective, and understanding.

After the second full day, covering Topics 8-15, students are generally restless. The second day is exclusively classroom lecture with no hands-on time except for homework. They have been asked to absorb almost the whole of the structure of SNTEMP, with little emphasis on the functionality. Questions usually revolve around “Now, how do we make this baby go,” which is fine as that is today’s subject. As always, the question/answer session is meant to be free roaming. Emphasize that no question is too silly or absurd. If someone has a question, it is a safe bet that someone else wants to ask that question too.

If you are taking the self-study class, take a moment and e-mail any questions to the instructor.

TOPIC #17: MISSING PIECES:
OPTIONS FOR HANDLING MISSING DATA

Time:	0.5 hours
Format:	Lecture/Reading
Assignment:	Review notebook material
Objectives:	(1) Learn what kind and how much missing data can be accommodated by model. (2) Understand distinction between filling and smoothing data. (3) Understand consequences of each option for data filling or smoothing missing. (4) Know where and how to select appropriate options.

You have seen that in the various node descriptors (remember which ones?) there have been "flags" for *filling* or *smoothing*. Or at least you have seen the words. But what do these mean and how should you use them?

It is not uncommon to have several nodes for which water temperature data must be supplied (**H**, **S**, **Q**, **V**, **R**), but that have missing data. I'm not talking about <u>no</u> data, as is the case with a zero flow headwater, or the case where you choose to use equilibrium temperatures for a top release reservoir, or ground temperature for a return flow. These the model supplies as so-called **defaults**. Rather I'm talking about cases of instrument failure, gaps in the USGS gage record, or suspicious data that was discarded during quality control (see Topic 25). Unfortunately, gaps in the record are more common than generally believed and SNTEMP has been developed with this in mind. The program's strength is also a weakness, as you will understand after you learn about filling and smoothing.

SNTEMP detects when required water temperature data are missing from the hydrology data file. It then attempts to fill those gaps using one of two regression models. The *default* is the so-called *transformed* model, which is explained more fully in Information Paper 16. Without going into the excruciating details, let's just say that it is the physically based temperature model transformed to a regression model's structure. It is most valuable for a free flowing stretch of stream with no discontinuity (structure, major tributary) anywhere near it upstream. Like any good regression model, it works by correlation of similar conditions, both meteorologically and hydrologically speaking, to fill in missing water temperature values.

The other option for regression is a simple *quadratic linear* model, not physically based, that generally performs better below discontinuities. You may wish to note the equation as it may prove useful to you for other reasons:

$$T_W = a_o + a_1\, T_a + a_2\, W_a + a_3\, R_h + a_4(S/S_o) + a_5\, H_{sx} + a_6\, Q + b_1T_a^2 + b_2W_a^2 + b_3R_h^2 + b_4(S/S_o)^2\, d + b_5H_{sx}^2 + b_6Q^2$$

where: T_a = air temperature
W_a = wind speed
R_h = relative humidity
S/S_o = sunshine ratio
H_{sg} = ground-level solar radiation
Q = discharge

Note: values are unit-less as shown here, but obviously have units during the application

Both regression models are meant to be used to fill a "relatively small" number of missing data points with respect to the *observed* values. What is relatively small? Well, it turns out that this question is moot because people will attempt to make it work regardless. The important thing is to understand the limitations. The first limit is the *minimum* number of observed temperatures. Recall that for any regression model, the minimum of observation must be the sum of the model's order plus the number of independent variables. Since however both models truncate terms if there are fewer observations than needed for the full model, SNTEMP's quadratic linear model requires a minimum of three observations while the transformed model requires four.

The second thing to keep in mind is the *representativeness* of the observations with respect to the pieces or block to be filled. What if, for example, all of the observed data is in the spring when air temperatures are cool and flows are high. Later, your thermograph came out of the water during late summer as the flows dropped and the sun blazed. Do you think that any regression model could do a good job of filling? Sure, it will guess (if it doesn't blow up mathematically), but the estimates may be quite poor. Regression models also require *stationarity*, meaning that the same processes are working throughout the data set. For example, if a dam is built part way through the period of record, post-dam data should not be used to fill pre-dam conditions.

Now, what's the difference between smoothing and filling? *Filling* is just what it says -- filling missing data gaps. *Smoothing* on the other hand is a slight misnomer as it really both fills and smooths. Smooth here means that SNTEMP first develops the regression model of your choice and then applies that model not only to fill, but also to completely replace the temperatures provided in the hydrology data file. Why smooth? Smoothing is typically applied only in cases of grab sample data on longer time steps, just as was done for the case study data set provided as class material. In that data set, the time step was one month and the long-term historical data was truly grab sample. A sample could have been taken at any time of day and any day in the month. Smoothing could also be used in cases where there are obvious outliers in existing data that are suspect due to an unknown quality control problem, such as weak batteries. Contemporary applications usually involve continuous monitoring, perhaps on an hourly basis; rarely would smoothing be advisable in such cases.

Now for the practicalities. Depending on what you want, set **F** or **S** flags for any hydrology nodes you deem necessary. This will be in column position 20 on the node line (see Topic 13). As mentioned, SNTEMP will detect the need to fill using the transformed regression even if you do nothing, but the **S** flag must be set if smoothing is desired.

Though we have yet to actually look at SNTEMP's output, one table (Table 7) will print a warning if the temperatures predicted with the chosen regression model differs from the observed values by more than 4°C. This may be useful in spotting outliers or bad input data. One somewhat confusing factor is that SNTEMP automatically runs all headwaters (both **S** and **H**) and **V** nodes through the internal regression models whether it need to or not. Don't be concerned if you see these showing up in Table 7.

One parting shot, but this is a secret -- don't tell anybody. SNTEMP will also fill missing flows at hydrology nodes. It does so by substituting the simple mean for the missing time period over the historical years of data. Need we say again: THIS IS NOT A HYDROLOGY MODEL!

RULES OF THUMB

Though we haven't covered SNTEMP's output yet, when the time comes, look at Table 7 and decide if R^2 is OK before proceeding with your model. Look for R^2 values greater than 0.9. If Table 7's *pseudo source distance* (transformed regression only) is negative, remove smoothing or change regression options.

SUGGESTED READINGS FOR TOPIC 17

Theurer, F. D., and K .A. Voos. 1982. IFG's instream water temperature model validation. Pages 513-518 *in* F. Kilpatrick and D. Matchett, editors. Proceedings of the Conference on water and energy: Technical and policy issues. American Society of Civil Engineers. Proceedings of the Hydraulics Conference, Pittsburgh, Penn., and Fort Collins, Colorado, May 23-26 and June 23-27, 1982.

REVIEW QUESTIONS FOR TOPIC 17

(1) Though we will mention filling and smoothing later when we discuss SNTEMP validation, what are the consequences of using filled and/or smoothed observed data when it comes time to assess SNTEMP's goodness of fit with observations at **V** nodes?

(2) What's wrong with using the historical mean flow to fill in a missing flow for a time period?

ANSWERS FOR TOPIC 17

(1) The model will compare simulated temperatures with “observed” temperatures. But if you have filled or smoothed, some of the “observed” temperatures haven’t really been observed. This will usually artificially inflate your goodness of fit statistics.

(2) Flows are rarely well correlated from year to year unless the time step is very large. Using the mean value is a pretty poor way to fill the data. Usually filling missing hydrology data by eye is a better choice -- and many better choices are available.

TOPIC #18: ORCHESTRATING SNTEMP: THE JOB CONTROL FILE

Time:	1 hour
Format:	Lecture/Reading
Assignment:	Review notebook material
Objectives:	Understand the control features in the job control file, including titles, I/O switches, global calibration parameters.

The **Job Control File** is the last of SNTEMP's input files we need to discuss. In addition to the actual data required by the system in order to perform simulations, information must be supplied that defines the size of the network, the extent of output desired, and other parameters. These variables are requests for verification tables, network node types where output is desired, number of years of historical and synthetic data, maximum number of time periods, number of nodes of various types in the system, temporal output designations, evaporation coefficients, maximum daytime air temperature regression coefficients, other calibration factors, air temperature correction factors, file names, and spatial output requests by stream name with from/to distances.

The job control file is the master file that controls the extent of the temperature model runs. The verification requests, output requests, years of data simulated, node counts, calibration factors, file names, and temporal and spatial output requests are in this file. The job control file is the first file used by the temperature model programs, and *the only input file that the program updates during execution of the model.*

The first two records of the job control file are title lines. The format for the job control file is described in Table III.2.

Table III.2. Job control file format.

Record No.	Field	Variable description
1	1 - 80	Title line
2	1 - 80	Subtitle line
- - - - - - - - - - - - -	Verification Tables: field should contain a “T” if requested, an “F” otherwise -	
3	1	Tables I through IX
3	2	Tables I, II, and III
3	3	Table I: Stream geometry after M nodes merged
3	4	Table III: Stream geometry after O nodes merged
3	5	Table III: Stream geometry after hydrology nodes merged
3	6	Tables IV and V
3	7	Table IV: Hydrology with missing flows added
3	8	Table V: Hydrology with lateral flows added
3	9	Table VI: Composite network - stream geometry, hydrology, and meteorology added
3	10	Table VII: Water temperature regression statistics
3	11	Table VIII: Water temperature data
3	12	Table IX: Validation statistics
3	13	Table X: Job Control

Table III.2. (continued)

Record No.	Field	Variable description
3	14	Table XI: Average and maximum temperature results. If field 14 is set to ' " ', the average and maximum temperature results will be created with titles in quotes for spreadsheet applications.
3	15 - 20	Reserved for future use
3	21 - 55	Unused
- - - - - - - - - - - -	Spatial Output Requests by Node Type; field should contain a "T" if requested, an "F" otherwise -	
3	56	All skeleton nodes
3	57	All hydrology nodes
3	58	All stream geometry nodes
3	59	All study nodes
3	60	The composite stream network
3	61	B nodes
3	62	C nodes
3	63	D nodes
3	64	E nodes
3	65	H nodes
3	66	J nodes
3	67	K nodes

Table III.2. (continued)

Record No.	Field	Variable description
3	68	M nodes
3	69	O nodes
3	70	P nodes
3	71	Q nodes
3	72	R nodes
3	73	S nodes
3	74	T nodes
3	75	V nodes
3	76	Unused flag
3	77	Hydrology warning message suppression flag
3	78	Shade data file present
3	79	Global shade model to be used
3	80	Regression need flag
- - - - - - - - - - - - - - - - - - General Numeric Information -		
4	1 - 8	Number of years of historical data
4	9 - 16	Number of years of synthetic data
4	17 - 24	First year of historical data, always use zero
4	25 - 32	Number of time periods per year
4	33 - 40	Number of shade nodes

Table III.2. (continued)

Record No.	Field	Variable description
4	41 - 48	Number of stream geometry nodes
4	49 - 56	Number of hydrology nodes
4	57 - 64	Number of study nodes
4	65 - 72	Total number of nodes in the system; may be 0
4	73 - 80	Number of nodes requiring regression analysis
- Node Count Information -		
5	1 - 8	Number of B nodes
5	9 - 16	Number of C nodes
5	17 - 24	Number of D nodes
5	25 - 32	Number of E nodes
5	33 - 40	Number of H nodes
5	41 - 48	Number of J nodes
5	49 - 56	Number of K nodes
5	57 - 64	Number of M nodes
5	65 - 72	Number of O nodes
5	73 - 80	Number of P nodes
6	1 - 8	Number of Q modes
6	9 - 16	Number of R nodes
6	17 - 24	Number of S nodes

Table III.2. (continued)

Record No.	Field	Variable description
6	25 - 32	Number of T nodes
6	33 - 40	Number of V nodes
- - - - - - - - - - - - - - - Time Period Output Sequence Numbers - - - - - - - - - - - - - - - - - -		
6	41 - 48	Starting year sequence number of output
6	49 - 56	Last year sequence number of output
6	57 - 64	First time period sequence number of output, always 1
6	65 - 72	Last time period sequence number of output, always last due to bug
6	73 - 80	Number of nodes in output tables, may be 0
- - - - - - - - - - - - - - - - - - User-Supplied Parameters -		
7	1 - 8	User-supplied evaporation factor (EFA), default = 40
7	9 - 16	User-supplied evaporation factor (EFB), default = 15
7	17 -24	User-supplied evaporation factor (EFC), default = 0 **Note:** above 3 factors refer to equation II (70) on page 11-30 of IP #16. The EFC factor is the coefficient for the square root of the wind speed, not mentioned in the manual. If you change one, you must enter all 3 values.
7	25 - 32	User-supplied Bowen ratio

Table III.2. (continued)

Record No.	Field	Variable description
7	33 - 40	lst maximum daily air temperature regression coefficient (a_0), default = 6.64
7	41 - 48	2nd maximum daily air temperature regression coefficient (a_1), default = -0.0014
7	49 - 56	3rd maximum daily air temperature regression coefficient (a_2), default = -5.27
7	57 - 64	4th maximum daily air temperature regression coefficient (a_3), default = 4.86 **Note:** above 4 factors require entering all if any one is changed
7	65 - 72	Starting time period sequence number for air temperature correction; blank (or zero) field defaults to first possible time period
7	73 - 80	Last time period sequence number for air temperature correction; blank (or zero) field defaults to last possible time period
- - - - - - - - - - - - - - - - - - Global Calibration Factors -		
8	1 - 8	Global air temperature calibration constant
8	9 - 16	Global air temperature calibration coefficient
8	17 - 24	Global wind speed calibration constant
8	25 - 32	Global wind speed calibration coefficient
8	33 - 40	Global humidity calibration constant
8	41 - 48	Global humidity calibration coefficient

Table III.2. (continued)

Record No.	Field	Variable description
8	49 - 56	Global sunshine calibration constant
8	57 - 64	Global sunshine calibration coefficient
8	65 - 72	Global solar calibration constant
8	73 - 80	Global solar calibration coefficient
- - - - - - - - - - - - - - - - - - Air Temperature Correction Factors - - - - - - - - - - - - - - - - - - -		
9	1 - 8	1st elevation
9	9 - 16	1st factor
9	17 - 24	2nd elevation
9	25 - 32	2nd factor
9	33 - 40	3rd elevation
9	41 - 48	3rd factor
9	49 - 56	4th elevation
9	57 - 64	4th factor
9	65 - 72	5th elevation
9	73 - 80	5th factor
- - - - - - - - - - - - - - - - - - - Input File Names -		
10	1 - 16	Time period file name, left justified
10	17 - 32	Meteorology file name, left justified

Table III.2. (concluded)

Record No.	Field	Variable description
10	33 - 48	Skeleton (not used)
10	49 - 64	Stream geometry file name, left justified
10	65 - 80	Study file name, left justified
11	1 - 16	Hydrology node file name, left justified
11	17 - 32	Hydrology data file name, left justified
11	33 - 48	Shade file name, left justified
11	49 - 80	Blank
- - - - - - - - - - - - - - - - - - Spatial Output Request by Stream Name - - - - - - - - - - - - - - - - -		
12	1 - 16	Local stream name for output
12	17 - 24	Starting distance for output
12	25 - 32	Ending distance for output
12	33 - 80	Blank
13 |21		Repeat of record 12 description

The distance fields on record 12 are inclusive. If left blank or if zeroes are input in both fields, the from/to distances default to all nodes located in the network with that stream name.

Example of the Job Control File looks like:

```
JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
Second title line
FFFFFFFFFFFFFTFFFFFF                                   FFFFFFFFFFFFFFFFFFTFFFFFTTT
              1.      0.     12.     16.     20.     12.     11.      0.      0.
              0.      0.      0.      0.      0.      0.      0.      0.      0.
              0.      0.      0.      1.      1.      3.      1.     12.      0.
 2.        .0000     .00   .0000     .00   .0000     .00   .0000     .00   .0000
 0.        .0000     .00   .0000     .00   .0000     .00   .0000     .00   .0000
 0.
 .00       .0000     .00   .0000     .00   .0000     .00   .0000     .00   .0000
 .00
KVRFTME.DAT     KVRFMET.DAT     dummy           KVRFSTR.DAT     KVRFSTD.DAT
 .00
KVRFHDR.DAT     KVRFHYD.DAT     KVRFSHD.DAT
               1       .0      .0
STR. NAME #
 STR. NAME #   2       .0      .0
 STR. NAME #   3       .0      .0
 STR. NAME #   4       .0      .0
 STR. NAME #   5       .0      .0
 STR. NAME #   6       .0      .0
 STR. NAME #   7       .0      .0
 STR. NAME #   8       .0      .0
 STR. NAME #   9       .0      .0
 STR. NAME #  10       .0      .0
```

Global calibration factors are used in the computer program to modify meteorological parameters according to the general form we have seen before:

$$Y_u = a_o + a_1y_o$$

where y_u = the modified time period meteorological parameter actually used by the model

y_o = the original input meteorological parameter

a_o = the calibration constant factor

a_1 = the calibration coefficient factor

The modified air temperature and wind speed parameters may be further modified with respect to time periods (see time period file). Blank (or zero) fields for both factors (constant and coefficient) defaults to no adjustment of the respective meteorological parameters. A non-zero in either field for a particular meteorological parameter will result in adjustment for that particular parameter.

The air temperature correction factors are used as indicated by the starting and last time period sequence numbers (record 7, columns 65-72 and 73-80). When the user does not believe that the default adiabatic air temperature correction model is applicable (-2°F per 1000 ft), these factors provide an alternative model. An example of a situation that would require such an alternative would be if you were simulating a coastal river that extends through a fog belt up into a more mesic climate, similar to an air temperature inversion. The computer program, when instructed, linearly interpolates between indicated elevations. The air temperature at the indicated elevations is calculated as equal to its associated factor times the air temperature at the meteorology station. Air temperature elevations less than the first and greater than the last are assumed to be equal to the first or last, respectively. All five sets, and the starting and last time period sequence numbers, must be initialized to correctly use this feature. Otherwise, all five sets, and the starting and last time period sequence numbers, must be set to zero to use the adiabatic air temperature correction.

SUGGESTED READINGS FOR TOPIC 18

None.

REVIEW QUESTIONS FOR TOPIC 18

No specific questions.

TOPIC #19: PUSHING THE BUTTONS:
RUNNING SNTEMP

Time:	0.5 hours
Format:	Lecture/Reading
Assignment:	Review notebook material
Objectives:	(1) Understand seven SNTEMP model sub-programs and their sequence. (2) Understand the job control update program (JBCNUD). (3) Understand which sub-programs produce which output files. (4) Understand how to run SNTEMP in a DOS environment.

EXECUTING SNTEMP IN A DOS ENVIRONMENT

The following material is more painful to read than it is to do, believe me. If every single step were to be written down, it would be simply awful. So here is a compromise that leans on your inherent skills. Learn as you go.

Configuring Your System

It is left to the user to decide how to arrange DOS directories, subdirectories and paths to control proper program flow with the desired data files. As distributed, this set of programs would require that all programs and data files reside in a single directory. It may be desirable to have all executable programs reside in a single directory and have user data sets reside in others.

Prior to running SNTEMP, you must first modify or create a CONFIG.SYS file for DOS to allocate enough room for the data files used by the programs. Specifically, the **CONFIG.SYS** must include the following statements:

```
BUFFERS=xx
FILES=xx            (where xx >= 10)
```

In addition, the following statement should be added to your path to allow access to the EXEcutable programs:

```
PATH=drive:\path\SNTEMP
```

Finally, some utilities, namely **TDATCHK**, requires a *DOS memory extender*, **DOSXMSF.EXE** that must also be in the path somewhere. In addition, if you are running under Windows 3.1, the line “device=dosxnt.386” must be in the [386Enh] section of the *system.ini* file in order to run the program in a DOSBPROMPT window. Modify the device line as appropriate if the DOSXNT.386 driver is not in the Windows directory. If running under Windows95, neither DOSXMSF.EXE or DOSXNT.386 are needed, thank goodness.

Invocation

SNTEMP is controlled by a batch file with the name SNTEMP.BAT. It is invoked simply by typing that name ‘SNTEMP’. The job control file name and a ‘Y’ or ‘N’ can optionally be specified on the command line. The Y and N indicate whether changes are needed to the job control file. Example:

```
SNTEMP KVRFJOB.DAT Y
```

This indicates that the job control file is KVRFJOB.DAT and changes to the control file are needed. For more details, you can type ‘SNTEMP ?’. The **LIST** utility is good for viewing the output files, which are unfortunately 132 columns wide.

Test Data Sets

The distribution disks contain a complete set of verification data files and output files that may be used both as a test of proper operation and as an example of how the programs look when running. These data files are contained in the files VRFIN.COM and VRFOUT.EXE, which must be “uncompressed” by typing VRFIN and VRFOUT.

To test SNTEMP on your system, start the batch file by typing ‘SNTEMP KVRFJOB.DAT N’. This will run SNTEMP using the Job Control file 'KVRFJOB.DAT with No changes to KVRFJOB.DAT.

After running the batch file, which may take up to 20 minutes depending on your hardware, you may compare the resulting files with their corresponding .OUT files either visually or by using the MS-DOS file compare utilities.

Job Control Update

JBCNUD is the first of several programs called by SNTEMP.BAT. Unlike the remaining programs, it is interactive, allowing you to control output requests, change certain default factors, change temporal calibration air temperature and wind speed factors, and correct node counts within the job control file. Not all of the parameters in the job control file can be changed under control the program. The following features are the output requests and parameters, which are under control of *JBCNUD*:

- verification tables
- spatial (by stream name and/or nodes) requests
- temporal (by years and/or time periods) output
- number of nodes in output tables
- set status of shade data file availability
- set status of global shade model mode
- set status of hydrology warning message suppression flag

* change default global calibration parameters
* change default temporal calibration factors
* number of nodes in skeleton, stream geometry, hydrology, study, and composite networks

The following features are the parameters in the job control file that are not presently controlled by the program:

* number of years of historical data
* number of years of synthetic data
* first year of historical data
* starting year sequence number of output
* last year sequence number of output
* first time period sequence number for air temperature correction
* last time period sequence number of output
* number of time period per year
* user-supplied Bowen ratio
* user-supplied wind factor parameters
* user-supplied maximum daily air temperature regression coefficients
* formatted input file names

If you haven't supplied it, *JBCNUD* prompts the user for the job control file name, which it requires to obtain and transfer information. The program will then prompt for each request and the user can respond “Y” or “N”. For example, if the user responds “Y” to the verification table requests, then the table as shown in Figure 19.1 will be printed on the screen. From the table, the user may choose any of the verification tables, which are requested by number. After the user enters his verification table requests, the program prompts for spatial output request designations and so on. The user may elect not to make a request from one of the program's selections in which case he simply enters “N”.

Figure 19.1 shows the available list of verification tables from the instream water temperature computer program. Figure 19.2 shows the request status. This example (Figure 19.2) shows that the only table requested was the job control file. Thus, after execution, a file named KVRJBCN will have been created. For the complete list of programs and their input and output files, see Table 19.3.

NOTE: Some user entries into *JBCNUD* will be to supply multiple answers, one per line. In such cases, a carriage return (<Enter>) is required on a blank line after the last entry to “return” to normal program prompting.

```
THE FOLLOWING VERIFICATION TABLE REQUESTS ARE AVAILABLE

REQUEST
NUMBER            TABLE NAME
   1         TABLE  I-IX:     ALL VERIFICATION TABLES
   2         TABLES I-III:    ALL THREE STREAM GEOMETRY TABLES
   3         TABLE I:         STREAM GEOMETRY AFTER 'M' NODES MERGED
   4         TABLE II;        STREAM GEOMETRY AFTER 'O' NODES MERGED
   5         TABLE III;       STREAM GEOMETRY AFTER HYDROLOGY NODES MERGED
   6         TABLE IV-V:      BOTH HYDROLOGY TABLES
   7         TABLE IV:        HYDROLOGY WITH MISSING FLOWS ADDED
   8         TABLE V:         HYDROLOGY WITH LATERAL FLOWS ADDED
   9         TABLE VI:        COMPOSITEBSTR. GEOM., HYDR., & MET. MERGED
  10         TABLE VII:       WATER TEMPERATURE REGRESSION STATISTICS
  11         TABLE IX:        VALIDATION STATISTICS
  12         TABLE X:         JOB CONTROL FILE
```

Figure 19.1. Prompt list of verification tables in *JBCNUD*.

The KVRJBCN file contains all of the variables present in the user's job control file, which allows easy reference for his job control file status. KVRJBCN is arranged in tabular fashion and each variable is described along with its current value for quick and easy reference.

```
                         VERIFICATION TABLE REQUESTS
TABLE
NUMBER              TABLES                                  T/F
-------------------------------------------------------------------------

     1     STREAM GEOMETRY AFTER ‘M’ NODES MERGED                     F
     2     STREAM GEOMETRY AFTER ‘O’ NODES MERGED                     F
     3     STREAM GEOMETRY AFTER HYDROLOGY NODES MERGED               F
     4     HYDROLOGY WITH MISSING FLOWS ADDED                         F
     5     HYDROLOGY WITH LATERAL FLOWS ADDED                         F
6          COMPOSITEBSTR. GEOM., HYDR., 7 MET. MERGED                 F
     7     WATER TEMPERATURE REGRESSION STATISTICS                    F
     8     WATER TEMPERATURE DATA                                     F
     9     VALIDATION STATISTICS                                      F
    10     JOB CONTROL FILE
```

Figure 19.2. A portion of the Table 10 list of verification table output requests.

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Table 19.3. Temperature Model Compute Program Sequence. File names listed in *italics* are binary files and should not be edited.

PROGRAM	FUNCTION	INPUT FILES	OUTPUT FILES
JBCNUD (job control update)	Query user for options and global calibration values. Count node types.	JOB CONTROL TIME PERIOD METEOROLOGY STREAM GEOMETRY	**Table 10 =** KVRJBCN JOB CONTROL (UPDATED) *KJOBCN1*
STRGEM (stream geometry)	Computer average elevations, latitudes, slopes. Add “M” modes & "O" nodes. Determine defaults. Verify network integrity.	*KJOBCN1* STREAM GEOMETRY STUDY FILE HYDROLOGY NODE FILE METEOROLOGY FILE	**Tables 1, 2, & 3** = KVRSTRG KBJOBCN1 (UPDATED) *KSTRMGM*
HYDROL (hydrology)	Compute missing flows. Adds lateral temperatures. Compute lateral and intermediate flows.	*KJOBCN1* *KSTRMGM* HYDROLOGY NODE FILE HYDROLOGY DATA FILE METEOROLOGY FILE TIME PERIOD FILE	**Tables 4 & 5** = KVRHYDR *KJOBCN1* (UPDATED) *KQSTATS* *KHYDROL*
METROL (meteorology)	Compute time specific meteorology, e.g. solar, adiabatic corrections, shade.	*KJOBCN1* *KSTRMGM* *KHYDROL* METEOROLOGY FILE TIME PERIOD FILE SHADE FILE (OPTIONAL)	**Table 6** = KVRMETR KJOBCN1 (UPDATED) *KMERGE*
REGTWO (regression)	Fill in missing temperature values using regressions.	*KJOBCN1* *KMERGE* TIME PERIOD FILE	**Table 7** = KVREGTW *KJOBCN1* (UPDATED) *KMERGE*
TRNSPT (transport)	Compute water temperatures using physical processes.	*KJOBCN1* *KMERGE* METEOROLOGY FILE	**Table 8** = KVRTRNS **Table 11** = KVRTMP *KTRNSPT*
VSTATS (validation statistics)	Compute validation statistics.	*KJOBCN1* *KVSTATS* TIME PERIOD FILE	**Table 9** = KVRSTAT JOB CONTROL (UPDATED)

RULES OF THUMB

> "The sad thing about artificial intelligence is that it lacks artifice and therefore intelligence." - Jean Baudrillard

Bluff your way through until you get the hang of it. Be curious; you can't hurt anything.

SUGGESTED READINGS FOR TOPIC 19

Look carefully at the SNTEMP.BAT file. Also, look for an alternative batch file contained in the FAQ at http://www.mesc.usgs.gov/sre/sntemp_faq/sntemp_faq.htm that may be more appealing to you.

REVIEW QUESTIONS FOR TOPIC 19

No specific questions.

TOPIC #20: QUALITY ASSURANCE: CHECKING THAT SNTEMP IS GETTING THE INPUT YOU WANT

Time:	0.5 hours
Format:	Lecture/Reading
Assignment:	Review notebook material
Objectives:	(1) Understand the spectrum of output files from SNTEMP.
	(2) Know where to look for echoes of the input data.
	(3) Learn how to spot (and fix) potential or actual errors.

On the pages that follow, you will find a complete (except for KVRTMP), but abbreviated, set of output files from SNTEMP resulting from the Upper Colorado data set we have been using in examples. It is important to learn what is in each table, which tables are valuable at which step in the simulation process, and which may not be so valuable.

Briefly, **Tables I-III** are produced by the stream geometry program (*STRGEM*), appear in the **KVRJBCN** file, and simply reflect increasing levels of detail as the program runs. Assuming that no run-time error has been detected in *STRGEM*, only Table III warrants attention, and then only to verify input. Stream gradient and ground temperatures have been calculated from the elevations. As with almost all of the tables produced by SNTEMP, the first part of the table tells generally what the program has done up to the point of table production, which is why it may be useful in debugging. Also, the job control file is echoed at the top of the table and you can follow its updates, if any, as they are made.

Tables IV-V, which may be found in the file **KSTRMGM**, come out of the hydrology program *HYDROL*. Again, assuming no problems, Table V is the only one necessary, and then usually only for data checking, though Table IV does report missing temperature values. Lateral flows and temperatures have been calculated. A minus one (-1.00) value here and in other tables signifies missing data, at least up to that point in the simulation model's progress.

Table VI results from the meteorology program *METROL* and may be found in the file **KVRMETR**. It is useful for data verification and shows the model's internal calibration factors for solar radiation, all of which should usually be very close to 1.0 and all between 0.9 and 1.1. These factors are the ratio of what the model calculates as ground-level solar radiation and what was supplied by you, if any, on a time period by time period basis. These ratios are then applied every year to the calculated values in the model. Table VI essentially contains everything necessary to calculate heat flux.

Table VII from the **KVREGTW** file displays the results of the filling/smoothing regressions performed by *REGTWO*. These should be carefully examined for goodness-of-fit of the regression models. Warnings may appear in this file as well. Look for high R-values and low error values. The *pseudo source distance* should be positive.

Table VIII is the principal table of modeling results coming from the *TRNSPT* program and may be found in **KVRTRNS**. Like most of the other tables, however, it is formatted for a line printer. **Table XI** in the **KVRTMP** file contains the same information as Table VIII but may be more useful in importing into spreadsheets, etc. Ignore the *K1* and *K2* columns.

Table IX contains the goodness-of-fit statistics coming from the *VSTATS* program. This information may be found in the **KVRSTAT** file and is critical for calibration, but not “what if” analyses. It is also the principal source of input for the EXERR program. Again, look for high R-values and low error values. We will talk about calibration more in a later topic.

Table X is an echo of the job control data, useful for verification, that is found in the **KVRJBCN** file.

Unfortunately, unlike with SNTEMP’s input files, it is not possible to control the names of the output files. One could, of course, modify the **SNTEMP.BAT** file to do some renaming if you please. See the FAQ at http://www.mesc.usgs.gov/sre/sntemp_faq/sntemp_faq.htm.

```
************* TABLE I: STREAM GEOMETRY AFTER 'M' NODES MERGED *************
     BEGIN STREAM GEOMETRY VERIFICATION OF 'ADDCHG' PROGRAM. THE PURPOSE OF THIS PROGRAM IS TO:
            ADD'M' NODES TO THE STREAM GEOMETRY ('KGNSTRG') FILE WHEN THE ELEVATION BETWEEN THE UPSTREAM & DOWNSTREAM SUBREACH NODES
            WOULD OTHERWISE EXCEED 300 METERS;
            CALCULATE THE AVERAGE LATITUDES & ELEVATIONS FOR THE REACH;
            CALCULATE THE STREAM GRADIENT & STREAMBED TEMPERATURE;
 (1)
            CREATE THE UNFORMATTED 'KSTRMGM' FILE.
 THIS VERIFICATION IS THE FORMATTED VERSION OF 'KSTRMGM'.
 (2)
 (3)
 (4)
 JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
 TEMPERATURE MODEL MICRO TEST SET
 TFFFFFFFFFFFTFFFFFFF                                FFFFTFFFFFFFFFFFFFFFFTTTT
               1.      0.     12.     16.     20.     12.     11.      0.      0.
               0.      0.      0.      0.      0.      0.      0.      0.      0.
               0.      0.      0.      1.      1.      3.      1.     12.      0.
           0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 2.
           0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 0.
           0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 0.00
 KVRFTME.DAT     KVRFMET.DAT     dummy           KVRFSTR.DAT     KVRFSTD.DAT
 0.00
 KVRFHDR.DAT     KVRFHYD.DAT     KVRFSHD.DAT
 0.00
 GREEN RIVER        423.2   556.7
 YAMPA RIVER        556.7   681.5
              3     0.0     0.0
 STR. NAME #
 ** JOB CONTROL DATA **
             10     0.0     0.0
 STR. NAME #
-----------------------------------------------------------------------------------------------------
       ----STREAM----- NODE       DIST.      AVERAGE        N      STR.  -STREAM WIDTH-   ----SHADE----   GRND.    THERM.
NODE       NAME       TYPE                 LAT.  ELEV.             GRAD.   COEF.    EXP.    MIN.    MAX.   TEMP.    GRAD.
 NO.                                      (RAD)    (M)   (----)   (M/M)     (M)  (----)   (DEC)   (DEC)     (C)(J/M2/S/C)
-----------------------------------------------------------------------------------------------------------------------------
       GREEN RIVER     S          661.3 0.71369   1671.   0.030 0.00164   60.96  0.0000  0.0001  0.0564   10.21    1.65
       GREEN RIVER     C          617.9 0.71180   1630.   0.030 0.00030   91.44  0.0000  0.0022  0.0089   10.48    1.65
1
 2
       GREEN RIVER     B          556.7
 . . . YAMPA RIVER     H          681.5 0.70686   1805.   0.030 0.00000   76.20  0.0000  0.0000  0.0004    9.34    1.65
 5
       YAMPA RIVER     S          652.0 0.70701   1757.   0.030 0.00727   76.20  0.0000  0.0000  0.0004    9.65    1.65
 6
       YAMPA RIVER     B          638.8
 7
       LITTLE SNAKE    H          651.6 0.70730   1714.   0.030 0.00086   38.10  0.0000  0.0019  0.0066    9.93    1.65
 8
       LITTLE SNAKE    T          638.8
 9
 10    YAMPA RIVER     J          638.8 0.70730   1705.   0.030 0.00062   45.72  0.0000  0.0001  0.0019    9.99    1.65
 11    YAMPA RIVER     T          556.7
 14    GREEN RIVER     J          556.7 0.70715   1526.   0.030 0.00181   76.20  0.0000  0.0000  0.6363   11.16    1.65
 15    GREEN RIVER     C          537.4 0.70686   1506.   0.030 0.00053  121.92  0.0000  0.0036  0.0141   11.30    1.65
 16
 . . . GREEN RIVER     E          399.0
 20-----------------------------------------------------------------------------------------------------------------------------

 (KM)

NORMAL COMPLETION OF 'ADDCHG'.
```

```
************** TABLE II: STREAM GEOMETRY AFTER 'O' NODES MERGED **************
    BEGIN STREAM GEOMETRY VERIFICATION OF 'ADDOUT' PROGRAM. THE PURPOSE OF THIS PROGRAM IS TO:
          MERGE THE OUTPUT ('O') NODES FROM THE STUDY ('KGNSTDY') FILE WITH THE STREAM GEOMETRY ('KSTRMGM') FILE;
          CREATE THE UNFORMATTED 'KSTRMGM' FILE.
    THIS VERIFICATION IS THE FORMATTED VERSION OF THE 'KSTRMGM' FILE.

(1)
(2)
JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
TEMPERATURE MODEL MICRO TEST SET
TFFFFFFFFFFFTFFFFFFF                               FFFFTFFFFFFFFFFFFFFFFTTTT
              1.      0.     12.     16.     20.     12.     11.      0.      0.
              0.      0.      0.      0.      0.      0.      0.      0.      0.
              0.      0.      0.      1.      1.      3.      1.     12.      0.
2.        0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
0.        0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
0.00      0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
0.00
0.00
KVRFTME.DAT     KVRFMET.DAT     dummy           KVRFSTR.DAT     KVRFSTD.DAT
KVRFHDR.DAT     KVRFHYD.DAT     KVRFSHD.DAT
GREEN RIVER        423.2   556.7
YAMPA RIVER        556.7   681.5
             3     0.0     0.0
STR. NAME #

**·JOB CONTROL DATA **
            10     0.0     0.0
STR. NAME #
-------------------------------------------------------------------------------------------------------------------------------
       ----STREAM----- NODE       DIST.      AVERAGE        N      STR.  -STREAM WIDTH-   ----SHADE----   GRND.    THERM.
NODE        NAME       TYPE                LAT.  ELEV.             GRAD.   COEF.   EXP.    MIN.    MAX.   TEMP.    GRAD.
 NO.                                      (RAD)    (M)    (----)   (M/M)     (M)  (----)  (DEC)   (DEC)     (C)(J/M2/S/C)
 ------------------------------------------------------------------------------------------------------------------------------
       GREEN RIVER     S          661.3 0.71369   1671.   0.030 0.00164   60.96  0.0000  0.0001  0.0564   10.21    1.65
       GREEN RIVER     C          617.9 0.71180   1630.   0.030 0.00030   91.44  0.0000  0.0022  0.0089   10.48    1.65
1      GREEN RIVER     C          580.8 0.71035   1595.   0.030 0.00417   45.72  0.0000  0.0962  0.2014   10.71    1.65
 2     GREEN RIVER     C          566.4 0.70889   1554.   0.030 0.00216   60.96  0.0000  0.1591  0.3004   10.98    1.65
 3     GREEN RIVER     B          556.7 0.00000      0.   0.000 0.00000    0.00  0.0000  0.0000  0.0000    0.00    0.00
 4     YAMPA RIVER     H          681.5 0.70686   1805.   0.030 0.00000   76.20  0.0000  0.0000  0.0004    9.34    1.65
 5     YAMPA RIVER     S          652.0 0.70701   1757.   0.030 0.00727   76.20  0.0000  0.0000  0.0004    9.65    1.65
 6     YAMPA RIVER     B          638.8 0.00000      0.   0.000 0.00000    0.00  0.0000  0.0000  0.0000    0.00    0.00
 7     LITTLE SNAKE    H          651.6 0.70730   1714.   0.030 0.00086   38.10  0.0000  0.0019  0.0066    9.93    1.65
 8     LITTLE SNAKE    T          638.8 0.00000      0.   0.000 0.00000    0.00  0.0000  0.0000  0.0000    0.00    0.00
 9
 10    YAMPA RIVER     J          638.8 0.70730   1705.   0.030 0.00062   45.72  0.0000  0.0001  0.0019    9.99    1.65
 11    YAMPA RIVER     C          627.5 0.70744   1638.   0.030 0.00304   45.72  0.0000  0.0000  0.0498   10.43    1.65
 12    YAMPA RIVER     C          585.7 0.70744   1559.   0.030 0.00107   45.72  0.0000  0.0000  0.7673   10.95    1.65
 13    YAMPA RIVER     T          556.7 0.00000      0.   0.000 0.00000    0.00  0.0000  0.0000  0.0000    0.00    0.00
 14    GREEN RIVER     J          556.7 0.70715   1526.   0.030 0.00181   76.20  0.0000  0.0000  0.6363   11.16    1.65
 15    GREEN RIVER     O          423.2 0.70279   1430.   0.030 0.00030   91.44  0.0000  0.0004  0.0018   11.79    1.65
 20    GREEN RIVER     E          399.0 0.00000      0.   0.000 0.00000    0.00  0.0000  0.0000  0.0000    0.00    0.00
 (KM)
 21-----------------------------------------------------------------------------------------------------------------------------


NORMAL COMPLETION OF 'ADDOUT'.
```

```
************************************ TABLE III: STREAM GEOMETRY AFTER HYDROLOGY NODES MERGED *************************************

          MERGE THE HYDROLOGY ('D', 'K', 'P', 'Q', 'R', AND 'V') NODES FROM THE HYDROLOGY ('KGNSHDR') FILE WITH THE STREAM
BEGIN STREAM GEOMETRY VERIFICATION OF 'ADDHYD' PROGRAM. THE PURPOSE OF THIS PROGRAM IS TO:
          CREATE THE UNFORMATTED 'KSTRMGM' FILE.
THIS VERIFICATION IS THE FORMATTED VERSION OF THE 'KSTRMGM' FILE.
(1)

(2)
JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
GEOMETRY ('KSTRMGM') FILE:
TEMPERATURE MODEL MICRO TEST SET
TFFFFFFFFFFFTFFFFFFF                                   FFFFTFFFFFFFFFFFFFFFFFTTTT
              1.      0.     12.     16.     20.     12.     11.      0.      0.
              0.      0.      0.      0.      0.      0.      0.      0.      0.
              0.      0.      0.      1.      1.      3.      1.     12.      0.
          0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
2.        0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
0.
0.00      0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
0.00
KVRFTME.DAT     KVRFMET.DAT     dummy           KVRFSTR.DAT     KVRFSTD.DAT
0.00
KVRFHDR.DAT     KVRFHYD.DAT     KVRFSHD.DAT
GREEN RIVER        423.2   556.7
YAMPA RIVER        556.7   681.5
               3     0.0     0.0
STR. NAME #

** JOB CONTROL DATA **
              10     0.0     0.0
STR. NAME #
-----------------------------------------------------------------------------------------------------------------------------
      ----STREAM----- NODE       DIST.      AVERAGE        N      STR.  -STREAM WIDTH-   ----SHADE----   GRND.    THERM.
NODE       NAME       TYPE                   LAT.  ELEV.          GRAD.   COEF.   EXP.    MIN.    MAX.   TEMP.    GRAD.
 NO.                                        (RAD)    (M)   (----)  (M/M)     (M)  (----)  (DEC)   (DEC)     (C)(J/M2/S/C)
-----------------------------------------------------------------------------------------------------------------------------
      GREEN RIVER     S          661.3 0.71369   1671.   0.030 0.00164   60.96  0.0000  0.0001  0.0564   10.21    1.65
      GREEN RIVER     C          617.9 0.71180   1630.   0.030 0.00030   91.44  0.0000  0.0022  0.0089   10.48    1.65
1     GREEN RIVER     C          580.8 0.71035   1595.   0.030 0.00417   45.72  0.0000  0.0962  0.2014   10.71    1.65
 2    GREEN RIVER     C          566.4 0.70889   1554.   0.030 0.00216   60.96  0.0000  0.1591  0.3004   10.98    1.65
 3    GREEN RIVER     B          556.7
 4    YAMPA RIVER     H          681.5 0.70686   1805.   0.030 0.00000   76.20  0.0000  0.0000  0.0004    9.34    1.65
 5    YAMPA RIVER     S          652.0 0.70701   1757.   0.030 0.00727   76.20  0.0000  0.0000  0.0004    9.65    1.65
 6    YAMPA RIVER     B          638.8
 7    LITTLE SNAKE    H          651.6 0.70730   1714.   0.030 0.00086   38.10  0.0000  0.0019  0.0066    9.93    1.65
 8    LITTLE SNAKE    T          638.8
 9
 10   YAMPA RIVER     J          638.8 0.70730   1705.   0.030 0.00062   45.72  0.0000  0.0001  0.0019    9.99    1.65
 11   YAMPA RIVER     C          627.5 0.70744   1638.   0.030 0.00304   45.72  0.0000  0.0000  0.0498   10.43    1.65
 12   YAMPA RIVER     C          585.7 0.70744   1559.   0.030 0.00107   45.72  0.0000  0.0000  0.7673   10.95    1.65
 13   YAMPA RIVER     T          556.7
 14   GREEN RIVER     J          556.7 0.70715   1526.   0.030 0.00181   76.20  0.0000  0.0000  0.6363   11.16    1.65
 15   GREEN RIVER     V 1S       485.9 0.70279   1430.   0.030 0.00030   91.44  0.0000  0.0004  0.0018   11.79    1.65
 20   GREEN RIVER     O          423.2 0.70279   1430.   0.030 0.00030   91.44  0.0000  0.0004  0.0018   11.79    1.65
(KM)
 21   GREEN RIVER     E          399.0
 22
```

```
************* TABLE IV: HYDROLOGY WITH MISSING FLOWS ADDED *************
     BEGIN HYDROLOGY VERIFICATION OF 'HYDFIL' PROGRAM. THE PURPOSE OF THIS PROGRAM IS:
            FILL IN IS HISTORICAL FLOWS WITH A 'BEST' ESTIMATE BASED ON AVAILABLE DATA;
            FLAG ANY MISSING, BUT NECESSARY, INITIAL WATER TEMPERATURES WITH A '-1.';
            FILL IN ANY MISSING LATERAL INFLOW WATER TEMPERATURES WITH THE LOCAL MEAN ANNUAL AIR TEMPERATURES;
 (1)        CREATE THE UNFORMATTED 'KHYDR2&3' FILES.
 (2)
 THIS VERIFICATION IS A FORMATTED VERSION OF THE 'KHYDR4' FILE.
 (3)
 (4)
 JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
 TEMPERATURE MODEL MICRO TEST SET
 TFFFFFFFFFFFFTFFFFFFF                                  FFFFTFFFFFFFFFFFFFFFFFTTTT
              1.      0.     12.     16.     20.     12.     11.     22.      0.
              0.      0.      0.      0.      0.      0.      0.      0.      0.
              0.      0.      0.      1.      1.      3.      1.     12.     10.
          0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 2.
          0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 0.
          0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 0.00
 KVRFTME.DAT     KVRFMET.DAT     dummy           KVRFSTR.DAT     KVRFSTD.DAT
 0.00
 KVRFHDR.DAT     KVRFHYD.DAT     KVRFSHD.DAT
 0.00
 GREEN RIVER        423.2   556.7
 YAMPA RIVER        556.7   681.5
               3     0.0     0.0
 STR. NAME #
 ** JOB CONTROL DATA **
              10     0.0     0.0
 STR. NAME #

 $$$-WARNING!  MISSING DATA IN REQUIRED KNOWN WATER TEMPERATURE FIELD.  THE


 REQUESTED REGRESSION MODEL WILL BE USED TO FILL THE FOLLOWING MISSING
 REQUIRED KNOWN WATER TEMPERATURE FIELDS:
                  NODE     DIST.     YEAR       TIME     TYPE
                  TYPE     (KM)                PERIOD     DATA

 STREAM
 YAMPA RIVER        H     681.5   1981-82       OCT  TEMPERATURE
                                                     TEMPERATURE
 NAME                                                TEMPERATURE
                                                     TEMPERATURE
                                                     TEMPERATURE
                                                     TEMPERATURE
                                                     TEMPERATURE
                                                     TEMPERATURE
                                                     TEMPERATURE
                                                     TEMPERATURE
                                                     TEMPERATURE
                                                     TEMPERATURE
```

```
 NOV
 DEC
 JAN
 MARCH
```

```
------------------------------------------------------------------------------------------------------------------------------------
 NODE  ----STREAM---- NODE      STREAM    YEAR    TIME   INIT. --TEMPERATURE--  NO. OF    MEAN    STD.:
         NAME         TYPE       DIST.            PER.    FLOW   INIT. LATERAL  POINTS    FLOW    DEV.:         REMARKS
 NO.                                                     (CMS)    (C)     (C)             (CMS)   (CMS):
 ------------------------------------------------------------------------------------------------------------------------------------
                      S 1S2      661.3 1962-63     OCT  22.010    8.82   10.21       2  31.460  13.364: FLAMING GORGE DAM
                                                         2.550    4.27   10.21       2  19.185  23.525:
1 GREEN RIVER                                            7.600    0.59   10.21       2  21.880  20.195:
                                                        10.400    2.32   10.21       2  24.245  19.580:
                                                        13.240    1.59   10.21       2  44.155  43.720:
                                                         2.990    1.93   10.21       2  23.070  28.397:
                                                         3.790    2.41   10.21       2  35.025  44.173:
                                                         3.690    4.03   10.21       2  23.935  28.631:
                                                         3.540    5.28   10.21       2  22.050  26.177:
                                                         2.950    6.33   10.21       2  21.540  26.290:
                                                         2.870    6.95   10.21       2  26.585  33.538:
                                                         3.190    5.48   10.21       2  34.400  44.138:
                                                   OCT  40.910   10.62   10.21       2  31.460  13.364:
                                                        35.820    7.53   10.21       2  19.185  23.525:
                                                        36.160    4.59   10.21       2  21.880  20.195:
                                                        38.090    4.43   10.21       2  24.245  19.580:
 (KM)                                                   75.070    4.00   10.21       2  44.155  43.720:
                                                        43.150    4.50   10.21       2  23.070  28.397:
                                                        66.260    4.91   10.21       2  35.025  44.173:
                                                        44.180    8.20   10.21       2  23.935  28.631:
                                                        40.560   12.02   10.21       2  22.050  26.177:
                                                        40.130   13.00   10.21       2  21.540  26.290:
                                                        50.300   13.00   10.21       2  26.585  33.538:
                                                        65.610   12.95   10.21       2  34.400  44.138:
                                                   OCT  51.570    9.20   10.21       2  31.460  13.364:
                                                        52.940    8.37   10.21       2  19.185  23.525:
                                                        57.040    6.86   10.21       2  21.880  20.195:
                                                        53.400    4.71   10.21       2  24.245  19.580:
                                                        54.800    3.83   10.21       2  44.155  43.720:
 NOV                                                    47.660    3.86   10.21       2  23.070  28.397:
 DEC                                                    54.130    4.96   10.21       2  35.025  44.173:
 JAN                                                    58.660    6.18   10.21       2  23.935  28.631:
 FEB
 MARCH                                                  66.350    7.88   10.21       2  22.050  26.177:
 APRIL
 1981-82                                                60.380    9.29   10.21       2  21.540  26.290:
                                                        56.840    9.85   10.21       2  26.585  33.538:
 MAY                                                    51.930    9.83   10.21       2  34.400  44.138:
 JUNE--------------------------------------------------------------------------------------------------------------------------------
 JULY
 AUGUST

 SEPT

 NOV
 DEC
 JAN
 FEB
 MARCH
 APRIL
 NORMAL
 MAY
 JUNE
 JULY
 AUGUST

 SEPT

 NOV
 DEC
 JAN
 FEB
 MARCH
 APRIL
```

```
----------------------------------------------------------------------------------------------------------------------------------
 NODE  ----STREAM---- NODE      STREAM    YEAR     TIME   INIT. --TEMPERATURE--  NO. OF    MEAN    STD.:
         NAME         TYPE       DIST.             PER.    FLOW   INIT. LATERAL  POINTS    FLOW    DEV.:         REMARKS
 NO.
                                                          (CMS)     (C)     (C)           (CMS)   (CMS):
----------------------------------------------------------------------------------------------------------------------------------
                      B          556.7 1962-63      OCT  22.324                        2  32.840  14.872: YAMPA RIVER CONFLUENCE
                                                          4.087                        2  20.807  23.646:
2 GREEN RIVER                                             7.453                        2  22.039  20.628:
                                                         11.540                        2  25.930  20.350:
                                                         14.707                        2  47.612  46.535:
                                                          4.357                        2  24.759  28.853:
                                                          4.632                        2  34.186  41.796:
                                                          2.136                        2  19.778  24.949:
                                                          4.305                        2  16.773  17.632:
                                                          3.966                        2  23.344  27.405:
                                                          3.438                        2  28.097  34.873:
                                                          4.487                        2  36.474  45.236:
                                                    OCT  43.356                        2  32.840  14.872:
                                                         37.528                        2  20.807  23.646:
                                                         36.625                        2  22.039  20.628:
                                                         40.319                        2  25.930  20.350:
 (KM)                                                    80.517                        2  47.612  46.535:
                                                         45.162                        2  24.759  28.853:
                                                         63.740                        2  34.186  41.796:
                                                         37.419                        2  19.778  24.949:
                                                         29.241                        2  16.773  17.632:
                                                         42.723                        2  23.344  27.405:
                                                         52.756                        2  28.097  34.873:
                                                         68.461                        2  36.474  45.236:
                                                    OCT  52.736                        2  32.840  14.872:
                                                         54.123                        2  20.807  23.646:
                                                         58.009                        2  22.039  20.628:
                                                         55.017                        2  25.930  20.350:
                                                         57.614                        2  47.612  46.535:
 NOV                                                     50.531                        2  24.759  28.853:
 DEC                                                     53.956                        2  34.186  41.796:
 JAN                                                     56.518                        2  19.778  24.949:
 MARCH                                                   67.830                        2  16.773  17.632:
 FEB
 APRIL                                                   62.556                        2  23.344  27.405:
 1981-82                                                 58.123                        2  28.097  34.873:
 MAY                                                     52.749                        2  36.474  45.236:
 JUNE-----------------------------------------------------------------------------------------------------------------------------
 AUGUST
 JULY

 SEPT

 NOV
 DEC
 JAN
 MARCH
 FEB
 APRIL
 NORMAL
 MAY
 JUNE
 AUGUST
 JULY

 SEPT

 NOV
 DEC
 JAN
 MARCH
 FEB
 APRIL
```

```
 -----------------------------------------------------------------------------------------------------------------------------------
  NODE  ----STREAM---- NODE      STREAM    YEAR    TIME   INIT. --TEMPERATURE--  NO. OF    MEAN    STD.:
         NAME      TYPE       DIST.            PER.    FLOW   INIT. LATERAL  POINTS    FLOW    DEV.:          REMARKS
  NO.
                                                    (CMS)     (C)     (C)             (CMS)   (CMS):
  -----------------------------------------------------------------------------------------------------------------------------------
                     E          399.0 1962-63     OCT  32.274                       2  49.984  25.046: DUSCHESNE RIVER CONFLUENCE
                                                        18.438                       2  36.330  25.303:
 12 GREEN RIVER
                                                        14.960                       2  32.973  25.474:
                                                        21.140                       2  38.915  25.138:
                                                        32.351                       2  69.095  51.965:
                                                        26.928                       2  53.708  37.873:
                                                        57.470                       2 105.055  67.295:
                                                                                     2 232.560 108.343:
                                                        99.310                       2 198.395 140.127:
                                                        14.465                       2  88.019 104.021:
                                                        12.830                       2  46.508  47.628:
                                                        15.420                       2  52.371  52.257:
                                                  OCT  67.695                       2  49.984  25.046:
                                                        54.222                       2  36.330  25.303:
                                                        50.986                       2  32.973  25.474:
                                                        56.690                       2  38.915  25.138:
                                                                                     2  69.095  51.965:
 (KM)
                                                        80.489                       2  53.708  37.873:
                                                                                     2 105.055  67.295:
                                                                                     2 232.560 108.343:
                                                                                     2 198.395 140.127:
                                                                                     2  88.019 104.021:
                                                        80.186                       2  46.508  47.628:
                                                        89.323                       2  52.371  52.257:
                                                  OCT  68.371                       2  49.984  25.046:
                                                        69.381                       2  36.330  25.303:
                                                        70.080                       2  32.973  25.474:
                                                        68.010                       2  38.915  25.138:
                                                        76.683                       2  69.095  51.965:
  NOV                                                   85.054                       2  53.708  37.873:
  DEC                                                                                2 105.055  67.295:
  JAN                                                                                2 232.560 108.343:
  MARCH
  FEB                                                                                2 198.395 140.127:
  APRIL                                                                              2  88.019 104.021:
  1981-82
                                                        71.862                       2  46.508  47.628:
  MAY 155.950                                           61.740                       2  52.371  52.257:
  JUNE-------------------------------------------------------------------------------------------------------------------------------
  AUGUST
  JULY

  SEPT
 NORMAL COMPLETION OF 'HYDFIL'.

  NOV
  DEC
  JAN
  MARCH
  FEB 105.840
  APRIL 152.640
  NORMAL
  MAY 309.170
  JUNE 297.480
  AUGUST
  JULY 161.573

  SEPT


  NOV
  DEC
  JAN
  MARCH
  FEB
  APRIL 148.640
```

```
***************************************** TABLE V: HYDROLOGY WITH LATERAL FLOWS ADDED ******************************************

          COMPUTE LATERAL FLOWS FOR UPSTREAM NODES;
 BEGIN HYDROLOGY VERIFICATION OF 'LATFLO' PROGRAM. THE PURPOSE OF THIS PROGRAM IS:
          CREATE THE FINAL UNFORMATTED HYDROLOGY FILE.
 THIS VERIFICATION IS A FORMATTED VERSION OF THE 'KHYDR5' OR 'KHYDROL' FILE.

 (1)
 (2)
 JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
 TEMPERATURE MODEL MICRO TEST SET
 TFFFFFFFFFFFTFFFFFFF                                 FFFFTFFFFFFFFFFFFFFFFFTTTT
              1.      0.     12.     16.     20.     12.     11.     22.      0.
              0.      0.      0.      0.      0.      0.      0.      0.      0.
              0.      0.      0.      1.      1.      3.      1.     12.     10.
          0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 2.
          0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 0.
          0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 0.00
 KVRFTME.DAT     KVRFMET.DAT     dummy           KVRFSTR.DAT     KVRFSTD.DAT
 0.00
 KVRFHDR.DAT     KVRFHYD.DAT     KVRFSHD.DAT
 0.00
 GREEN RIVER        423.2   556.7
 YAMPA RIVER        556.7   681.5
               3     0.0     0.0
 STR. NAME #

 ** JOB CONTROL DATA **
              10     0.0     0.0
 STR. NAME #


                                 NORMAL      TIME PERIOD:    SEPT
 ---------------------------------------------------------------------------------------------------------------------
      ----STREAM---- NODE      STREAM  -----FLOW----- --TEMPERATURE--:
NODE
           NAME      TYPE       DIST.   INIT. LATERAL   INIT. LATERAL:          REMARKS
 NO.
                                        (CMS)(CMS/KM)     (C)     (C):
 ---------------------------------------------------------------------------------------------------------------------
                     S 1S2      661.3  51.930  0.0078    9.83   10.21: FLAMING GORGE DAM
                     B          556.7  52.749                        : YAMPA RIVER CONFLUENCE
                     H 1F       681.5   5.980  0.0078   18.30    9.34: MAYBELL
1 GREEN RIVER
 2 GREEN RIVER
                     S   5      652.0   6.211  0.0078   -1.00    9.65: CROSS MOUNTAIN
 3 YAMPA RIVER       B          638.8   6.314                        : LITTLE SNAKE CONFLUENCE
 4 YAMPA RIVER       H 1F       651.6   1.350  0.0078   15.62    9.93: LILY GAGE
 5 YAMPA RIVER       T          638.8   1.450                        : YAMPA CONFLUENCE
 6 LITTLE SNAKE      J          638.8   7.764  0.0078            9.99: LITTLE SNAKE JUNCTION
 7 LITTLE SNAKE      T          556.7   8.407                        : GREEN RIVER CONFLUENCE
 8 YAMPA RIVER
 YEAR:
                     J          556.7  61.156  0.0078           11.16: YAMPA RIVER JUNCTION
 9 YAMPA RIVER
 10 GREEN RIVER      V 1S       485.9  61.710           15.85        : JENSEN GAGE
 11 GREEN RIVER      E          399.0  61.740                        : DUSCHESNE RIVER CONFLUENCE
 ---------------------------------------------------------------------------------------------------------------------
 12 GREEN RIVER


                                 NORMAL      TIME PERIOD:     OCT
NORMAL COMPLETION OF 'LATFLO'.
 ---------------------------------------------------------------------------------------------------------------------
 (KM)
      ----STREAM---- NODE      STREAM  -----FLOW----- --TEMPERATURE--:
NODE
           NAME      TYPE       DIST.   INIT. LATERAL   INIT. LATERAL:          REMARKS
 NO.
                                        (CMS)(CMS/KM)     (C)     (C):
 ---------------------------------------------------------------------------------------------------------------------
                     S 1S2      661.3  51.570  0.0111    9.20   10.21: FLAMING GORGE DAM
                     B          556.7  52.736                        : YAMPA RIVER CONFLUENCE
                     H 1F       681.5   9.710  0.0112   11.90    9.34: MAYBELL
1 GREEN RIVER
 2 GREEN RIVER
 3 YAMPA RIVER
```

```
 YEAR:
```

```
                     S   5      652.0  10.039  0.0111   -1.00    9.65: CROSS MOUNTAIN
                     B          638.8  10.186                        : LITTLE SNAKE CONFLUENCE
4 YAMPA RIVER        H 1F       651.6   2.940  0.0112   10.23    9.93: LILY GAGE
5 YAMPA RIVER        T          638.8   3.083                        : YAMPA CONFLUENCE
6 LITTLE SNAKE       J          638.8  13.269  0.0111            9.99: LITTLE SNAKE JUNCTION
7 LITTLE SNAKE       T          556.7  14.184                        : GREEN RIVER CONFLUENCE
8 YAMPA RIVER        J          556.7  66.921  0.0111           11.16: YAMPA RIVER JUNCTION
9 YAMPA RIVER
10 GREEN RIVER       V 1S       485.9  67.710           10.88        : JENSEN GAGE
11 GREEN RIVER       E          399.0  68.371                        : DUSCHESNE RIVER CONFLUENCE
12 GREEN RIVER-----------------------------------------------------------------------------------------------------------
```

```
*************************************** TABLE VI: COMPOSITE-STR. GEOM., HYDR., & MET. MERGED ***************************************

 BEGIN FINAL HYDROLOGY, STREAM GEOMETRY, AND LOCAL METEOROLOGY VERIFICATION FOR THE COMPOSITE NETWORK. THE PURPOSE OF
 THIS PROGRAM IS TO:
 (1)       GENERATE THE SOLAR DATA;
 (2)       GENERATE THE SHADE DATA;
 (3)       DETERMINE THE LOCAL METEOROLOGY FOR EACH NODE;
 (4)       COMPLETE THE HYDROLOGY DATA AT EACH NON-HYDROLOGY NODE;
 (5)       MERGE ALL DATA AT EACH COMPOSITE NODE FOR ALL YEARS AND TIME PERIODS INTO A SINGLE DIRECT-ACCESS FILE.
 THIS VERIFICATION IS A TRUNCATED VERSION CONTAINING THE NEWLY CREATED DATA FOR 'KMERGE'.

 ** JOB CONTROL DATA **
 JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
 TEMPERATURE MODEL MICRO TEST SET
 TFFFFFFFFFFFTFFFFFFF                                   FFFFTFFFFFFFFFFFFFFFFTTTT
 2.            1.      0.     12.     16.     20.     12.     11.     22.      5.
 0.            0.      0.      0.      0.      0.      0.      0.      0.      0.
 0.00          0.      0.      0.      1.      1.      3.      1.     12.     10.
 0.00      0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 0.00      0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
           0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 KVRFTME.DAT     KVRFMET.DAT     dummy           KVRFSTR.DAT     KVRFSTD.DAT
 KVRFHDR.DAT     KVRFHYD.DAT     KVRFSHD.DAT
 GREEN RIVER        423.2   556.7
 YAMPA RIVER        556.7   681.5
 STR. NAME #     3    0.0     0.0
 STR. NAME #    10    0.0     0.0

 NORMAL COMPLETION OF 'METROL'.
CALIBRATION FACTORS FOR SOLAR RADIATION AT GROUND LEVEL:  LAT(RAD)=0.68271  ELEV(M)= 1475.  AVG. ANN. AIR TEMP(C)= 11.50
METEOROLOGY FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
 ------------------------------------------------------------------------------------------------------------------------------------
 TIME      SOLAR    TIME   SOLAR    TIME   SOLAR    TIME   SOLAR    TIME   SOLAR    TIME   SOLAR    TIME   SOLAR    TIME   SOLAR
 PERIOD   FACTOR  PERIOD  FACTOR  PERIOD  FACTOR  PERIOD  FACTOR  PERIOD  FACTOR  PERIOD  FACTOR  PERIOD  FACTOR  PERIOD  FACTOR
           (DEC)           (DEC)           (DEC)           (DEC)           (DEC)           (DEC)           (DEC)           (DEC)
 ------------------------------------------------------------------------------------------------------------------------------------
 OCT      1.0083     NOV  1.0008     DEC  0.8968     JAN  0.9921     FEB  0.9997   MARCH  1.0081   APRIL  0.9925     MAY  1.0003
 JUNE     0.9936    JULY  1.0002  AUGUST  1.0013    SEPT  1.0013
```

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                                                  NORMAL YEAR:    TIME PERIOD:     OCT                                         PAGE NO. 1
------------------------------------------------------------------------------------------------------------------------------------------
NODE ----STREAM---- NODE        STREAM    AIR     REL.    WIND    POSS.     ATM.   SOLAR   TOTAL     DAY      INITIAL          LATERAL
 NO.        NAME    TYPE         DIST.   TEMP.   HUMD.   SPEED     SUN      PRS.    RAD.   SHADE   LIGHT    FLOW   TEMP.     FLOW    TEMP.
                                  (KM)     (C)   (DEC)   (M/S)   (DEC)      (MB)(J/M2/S)   (DEC)    (HR)   (CMS)     (C)(CMS/KM)     (C)
------------------------------------------------------------------------------------------------------------------------------------------
 1 GREEN RIVER      S 1S2        661.3   11.43   0.480    3.53   0.730      826.   151.7  0.0272  10.830  51.570    9.20  0.0111   10.21
 2 GREEN RIVER      C            617.9   11.70   0.472    3.53   0.730      830.   152.1  0.0061  10.835  52.054          0.0111   10.21
 3 GREEN RIVER      C            580.8   11.93   0.466    3.53   0.730      834.   152.5  0.1645  10.838  52.467          0.0111   10.21
 4 GREEN RIVER      C            566.4   12.20   0.459    3.53   0.730      838.   152.8  0.2517  10.842  52.628          0.0111   10.21
 5 GREEN RIVER      B            556.7                                                                  52.736
 6 YAMPA RIVER      H 1F         681.5   10.56   0.505    3.53   0.730      812.   153.6  0.0001  10.847   9.710   11.90  0.0112    9.34
 7 YAMPA RIVER      S   5        652.0   10.87   0.496    3.53   0.730      817.   153.5  0.0001  10.846  10.039   -1.00  0.0111    9.65
 8 YAMPA RIVER      B            638.8                                                                  10.186
 9 LITTLE SNAKE     H 1F         651.6   11.15   0.488    3.53   0.730      822.   153.4  0.0048  10.846   2.940   10.23  0.0112    9.93
10 LITTLE SNAKE     T            638.8                                                                   3.083
11 YAMPA RIVER      J            638.8   11.21   0.486    3.53   0.730      823.   153.4  0.0004  10.846  13.269          0.0111    9.99
12 YAMPA RIVER      C            627.5   11.65   0.474    3.53   0.730      829.   153.2  0.0096  10.845  13.395          0.0111    9.99
13 YAMPA RIVER      C            585.7   12.17   0.460    3.53   0.730      838.   153.1  0.1254  10.845  13.861          0.0111    9.99
14 YAMPA RIVER      T            556.7                                                                  14.184
15 GREEN RIVER      J            556.7   12.38   0.454    3.53   0.730      841.   153.2  0.0743  10.846  66.921          0.0111   11.16
16 GREEN RIVER      C            537.4   12.52   0.450    3.53   0.730      843.   153.2  0.0098  10.847  67.136          0.0111   11.16
17 GREEN RIVER      C            526.1   12.70   0.446    3.53   0.730      846.   153.2  0.0098  10.847  67.262          0.0111   11.16
18 GREEN RIVER      C            510.1   12.88   0.441    3.53   0.730      849.   153.3  0.1315  10.849  67.440          0.0111   11.16
19 GREEN RIVER      C            502.0   13.01   0.437    3.53   0.730      851.   154.1  0.0011  10.856  67.531          0.0111   11.16
20 GREEN RIVER      V 1S         485.9   13.01   0.437    3.53   0.730      851.   154.1  0.0011  10.856  67.710   10.88  0.0076   11.79
21 GREEN RIVER      O            423.2   13.01   0.437    3.53   0.730      851.   154.1  0.0011  10.856  68.187          0.0076   11.79
22 GREEN RIVER      E            399.0                                                                  68.371
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                                        NORMAL       TIME PERIOD:    SEPT                                  PAGE NO. 1
-----------------------------------------------------------------------------------------------------------------------------------
                              STREAM    AIR     REL.     WIND    POSS.     ATM.    SOLAR   TOTAL     DAY       INITIAL          LATERAL
NODE ----STREAM---- NODE
 NO.        NAME     TYPE      DIST.   TEMP.    HUMD.    SPEED    SUN      PRS.     RAD.   SHADE    LIGHT    FLOW   TEMP.    FLOW     TEMP.
                                        (C)     (DEC)    (M/S)   (DEC)     (MB)(J/M2/S)   (DEC)     (HR)    (CMS)    (C)(CMS/KM)     (C)
-----------------------------------------------------------------------------------------------------------------------------------
  1 GREEN RIVER      S 1S2     661.3   18.27    0.404    4.02    0.790     826.    216.4  0.0139   12.220  51.930    9.83  0.0078    10.21
  2 GREEN RIVER      C         617.9   18.54    0.398    4.02    0.790     830.    216.7  0.0045   12.219  52.270          0.0078    10.21
  3 GREEN RIVER      C         580.8   18.77    0.393    4.02    0.790     834.    216.9  0.1380   12.219  52.560          0.0078    10.21
  4 GREEN RIVER      C         566.4   19.04    0.387    4.02    0.790     838.    217.1  0.2160   12.218  52.673          0.0078    10.21
  5 GREEN RIVER      B         556.7                                                                      52.749
  6 YAMPA RIVER      H 1F      681.5   17.40    0.426    4.02    0.790     812.    218.0  0.0000   12.217   5.980   18.30  0.0078
  7 YAMPA RIVER      S   5     652.0   17.71    0.418    4.02    0.790     817.    217.9  0.0000   12.217   6.211   -1.00  0.0078    9.34
  8 YAMPA RIVER      B         638.8                                                                       6.314                   9.65
  9 LITTLE SNAKE     H 1F      651.6   17.99    0.411    4.02    0.790     822.    217.8  0.0036   12.217   1.350   15.62  0.0078
 10 LITTLE SNAKE     T         638.8                                                                       1.450                   9.93
 11 YAMPA RIVER      J         638.8   18.05    0.410    4.02    0.790     823.    217.7  0.0000   12.217   7.764          0.0078
 12 YAMPA RIVER      C         627.5   18.49    0.399    4.02    0.790     829.    217.6  0.0003   12.217   7.853          0.0078    9.99
 13 YAMPA RIVER      C         585.7   19.01    0.387    4.02    0.790     838.    217.4  0.0017   12.217   8.180          0.0078    9.99
 14 YAMPA RIVER      T         556.7                                                                       8.407                   9.99
 15 GREEN RIVER      J         556.7   19.22    0.383    4.02    0.790     841.    217.4  0.0012   12.217  61.156          0.0078
 16 GREEN RIVER      C         537.4   19.36    0.379    4.02    0.790     843.    217.4  0.0072   12.217  61.307          0.0078    11.16
(KM)
 17 GREEN RIVER      C         526.1   19.54    0.376    4.02    0.790     846.    217.4  0.0072   12.217  61.395          0.0078    11.16
 18 GREEN RIVER      C         510.1   19.72    0.371    4.02    0.790     849.    217.4  0.0999   12.217  61.521          0.0078    11.16
YEAR:
 19 GREEN RIVER      C         502.0   19.85    0.369    4.02    0.790     851.    218.0  0.0008   12.215  61.584          0.0078    11.16
 20 GREEN RIVER      V 1S      485.9   19.85    0.369    4.02    0.790     851.    218.0  0.0008   12.215  61.710   15.85  0.0003    11.16
 21 GREEN RIVER      O         423.2   19.85    0.369    4.02    0.790     851.    218.0  0.0008   12.215  61.732          0.0003    11.79
 22 GREEN RIVER      E         399.0                                                                      61.740                   11.79
-----------------------------------------------------------------------------------------------------------------------------------


NORMAL COMPLETION OF 'METROL'.
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**************************************** TABLE VII: WATER TEMPERATURE REGRESSION STATISTICS ****************************************
                                                 THIS PROGRAM IS TO GENERATE THE REGRESSION COEFFICIENTS AND SUMMARY STATISTICS FOR
 THE VARIOUS OPTIONAL REGRESSION MODELS.  THE MODEL CAN BE USED TO:
 BEGIN WATER TEMPERATURE REGRESSION ANALYSIS.
           SMOOTH EXISTING DATA;
           FILL VOIDS IN EXISTING DATA;
           GENERATE DATA FOR SYNTHETIC YEARS.
 (1)
 (2)
 (3)
 THE FOLLOWING VERIFICATION TABLE CONTAINS SUMMARY STATISTICS FOR EACH NODE ASSOCIATED WITH OBSERVED WATER TEMPERATURES.  THE
 OBSERVED STATISTICS ARE FOR THE 'RAW' OR OBSERVED DATA.  THE PREDICTED STATISTICS ARE COMPARISONS OF THE PREDICTED VERSUS OBSERVED
 WATER TEMPERATURES FOR THE ENTIRE OBSERVED DATA SET.  THE PSEUDO-PHYSICAL STATISTICS ARE PHYSICAL INTERPRETATIONS OF THE TRANSFORMED
 REGRESSION MODEL COEFFICIENTS.  THE USE FIELD INDICATES HOW THE REGRESSION MODEL WAS USED FOR EACH RESPECTIVE NODE--'S' IS FOR
 SMOOTH EXISTING DATA, 'F' IS FOR FILLING VOIDS IN EXISTING DATA, AND 'G' IS FOR GENERATING DATA FOR SYNTHETIC YEARS ONLY.
 OBVIOUSLY, THE REGRESSION MODEL IS ALSO USED TO FILL VOIDS OR GENERATE SYNTHETIC DATA AS NECESSARY WHEN SMOOTHING DATA, AND TO GEN-

ERATE SYNTHETIC DATA AS NECESSARY WHEN FILLING DATA.

 JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
 TEMPERATURE MODEL MICRO TEST SET
 TFFFFFFFFFFFTFFFFFFF                                   FFFFTFFFFFFFFFFFFFFFFTTTT
              1.      0.     12.     16.     20.     12.     11.     22.      5.
              0.      0.      0.      0.      0.      0.      0.      0.      0.
              0.      0.      0.      1.      1.      3.      1.     12.     10.
 2.       0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 0.       0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 0.00     0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
 0.00
 KVRFTME.DAT     KVRFMET.DAT     dummy           KVRFSTR.DAT     KVRFSTD.DAT
 0.00
 KVRFHDR.DAT     KVRFHYD.DAT     KVRFSHD.DAT
 GREEN RIVER        423.2   556.7
 YAMPA RIVER        556.7   681.5
               3      0.0     0.0
 STR. NAME #

 ** JOB CONTROL DATA **
              10      0.0     0.0
 STR. NAME #


 --------------------------*----------------*-------------------------*--------------------*-*-----------------------------------------
                           * OBS. STATISTICS*    PRED. STATISTICS    *  PSEUDO-PHY. STAT. *U*
                           *  MEAN  STD. NO.* CORR. PROB.  MAX.  BIAS*  SOURCE  AVG. DELTA*S*
STREAM IDENTIFICATION
               TYPE  DIST.* TEMP.  DEV. PT.* COEF. ERROR ERROR ERROR*   DIST. TEMP. TEMP.*E*    REGRESSION MODEL OPTION
                             (C)   (C) (N)*   (R)   (C)   (C)   (C)*    (KM)   (C)   (C)* *
 --------------------------*----------------*-------------------------*--------------------*-*-----------------------------------------
 NAME
GREEN RIVER        S  661.30*  6.24  3.79  24*0.8808  1.21  3.07  0.25*                    *S* LINEAR STANDARD MULTIPLE--2ND DEGREE
 YAMPA RIVER       H  681.50* 10.93  8.18  12*0.9566  1.61  3.73  0.48*  -0.510 10.94 10.79*F* NON-LINEAR ZERO-LAT. FLOW HEAT TRANS.
 YAMPA RIVER       S  652.00*                *                        *                    * * FLOW THRU WATER TEMPERATURES
 LITTLE SNAKE      H  651.60*  9.88  7.56  11*0.9442  1.68 -3.40  0.53*   6.269  8.56  9.80*F* NON-LINEAR ZERO-LAT. FLOW HEAT TRANS.
 GREEN RIVER       V  485.90* 11.54  7.43  23*0.9897  0.72  2.39  0.15*  57.290  9.42  7.37*S* NON-LINEAR ZERO-LAT. FLOW HEAT TRANS.
 NODE
 ----------------------------------------------------------------------------------------------------------------------------------------


NORMAL COMPLETION OF 'REGTWO'.

 (KM)*
```

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******************************************** TABLE VIII: WATER TEMPERATURE DATA ********************************************

BEGIN INSTREAM WATER TEMPERATURE CALCULATIONS VERIFICATION OF 'NETWRK' PROGRAM. THE PURPOSE OF THIS PROGRAM IS TO:
(1)        DETERMINE THE PREDICTED WATER TEMPERATURE FOR EACH YEAR & TIME PERIOD AT EVERY NODE IN THE COMPOSITE NETWORK;
(2)        GENERATE THE VERIFICATION TABLE;
(3)        GENERATE THE UNFORMATTED OUTPUT FILE FOR THE OUTPUT REPORT GENERATOR AND/OR LINKAGE TO OTHER PROGRAMS.
THIS VERIFICATION IS THE FORMATTED VERSION OF 'KTRNSPT' FILE.

JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
TEMPERATURE MODEL MICRO TEST SET
TFFFFFFFFFFFTFFFFFFF                                   FFFFTFFFFFFFFFFFFFFFFFTTTF
              1.      0.     12.     16.     20.     12.     11.     22.      5.
              0.      0.      0.      0.      0.      0.      0.      0.      0.
              0.      0.      0.      1.      1.      3.      1.     12.     10.
2.        0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
0.        0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
0.00      0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
0.00
KVRFTME.DAT     KVRFMET.DAT     dummy           KVRFSTR.DAT     KVRFSTD.DAT
0.00
KVRFHDR.DAT     KVRFHYD.DAT     KVRFSHD.DAT
GREEN RIVER        423.2   556.7
YAMPA RIVER        556.7   681.5
              3      0.0     0.0
STR. NAME #
** JOB CONTROL DATA **
             10      0.0     0.0
STR. NAME #
```

```
YEAR:  NORMAL        TIME PERIOD:     OCT                                   PAGE NO. 1
 *---------------------------------------------------------------------------------------------------------------------------------*
 *-----STREAM IDENTIFICATION----:---WATER TEMP.----:----EQUILIBRIUM PARAMETERS-----:
 *NODE ----STREAM---- NODE STRM.:-AVG. DAILY-  MAX.:---AVG. DAILY-----:-MAX. DAILY-:
 * NO.      NAME      TYPE DIST.:  OBS. PRED. PRED.:    TE    K1    K2:    TE    K1:        REMARKS
 *                              :                  :       (J/M2(J/M2/:       (J/M2:                                          *
 *                              :   (C)   (C)   (C):   (C) /S/C) S/C2):   (C) /S/C):                                          *
 *----------------------------------------------------------------------------------------------------------------------------*----*
 *  1 GREEN RIVER      S   661.3:  8.06  8.06  9.10: 10.80 25.07-0.356: 18.11 31.92: FLAMING GORGE DAM                        *
 *  2 GREEN RIVER      C   617.9:        8.77 10.16: 10.56 24.92-0.358: 18.05 31.88: LITTLE BROWN PARK                        *
 *  3 GREEN RIVER      C   580.8:        9.34 10.42: 11.94 26.02-0.382: 18.25 32.16: LADORE CANYON
 *  4 GREEN RIVER      C   566.4:        9.53 10.87: 10.69 25.09-0.365: 16.73 30.49: HELLS HALF MILE                          *
 *  5 GREEN RIVER      B   556.7:        9.61 10.75:                  : 16.73 30.49: YAMPA RIVER CONFLUENCE                   *
 *  6 YAMPA RIVER      H   681.5: 11.90 11.90 11.90:  9.95 24.33-0.372: 17.66 31.29: MAYBELL                                  *
 *  7 YAMPA RIVER      S   652.0: 10.43 10.43 10.43: 10.50 24.77-0.368: 18.08 31.81: CROSS MOUNTAIN                           *
 *  8 YAMPA RIVER      B   638.8:       10.45 15.05:                  : 18.08 31.81: LITTLE SNAKE CONFLUENCE                  *
 *  9 LITTLE SNAKE     H   651.6: 10.23 10.23 13.34: 10.27 24.64-0.363: 17.87 31.61: LILY GAGE                                *
 * 10 LITTLE SNAKE     T   638.8:       10.25 13.91:                  : 17.87 31.61: YAMPA CONFLUENCE                         *
 * 11 YAMPA RIVER      J   638.8:       10.41 14.79: 10.36 24.71-0.371: 17.97 31.73: LITTLE SNAKE JUNCTION                    *
 * 12 YAMPA RIVER      C   627.5:       10.39 12.23: 10.84 25.13-0.373: 18.28 32.15: LILY PARK                                *
 * 13 YAMPA RIVER      C   585.7:       10.64 13.31: 10.50 24.94-0.370: 17.34 31.15: HARDING HOLE                             *
 * 14 YAMPA RIVER      T   556.7:       10.57 12.38:                  : 17.34 31.15: GREEN RIVER CONFLUENCE                   *
 * 15 GREEN RIVER      J   556.7:        9.81 11.10: 11.28 25.56-0.376: 18.25 32.22: YAMPA RIVER JUNCTION                     *
 * 16 GREEN RIVER      C   537.4:       10.00 11.31: 11.07 25.42-0.374: 18.45 32.47: ISLAND PARK                              *
 * 17 GREEN RIVER      C   526.1:       10.12 11.41: 12.33 26.44-0.394: 19.44 33.70: RAINBOW PARK                             *
 * 18 GREEN RIVER      C   510.1:       10.31 11.77: 11.09 25.49-0.376: 17.78 31.74: SPLIT MOUNTAIN                           *
 * 19 GREEN RIVER      C   502.0:       10.36 11.39: 11.37 25.72-0.381: 18.76 32.91: FLATLAND BELOW SPLIT MOUNTAIN            *
 * 20 GREEN RIVER      V   485.9: 12.19 10.48 11.43: 11.37 25.72-0.382: 18.76 32.91: JENSEN GAGE                              *
 * 21 GREEN RIVER      O   423.2:       10.84 11.77: 11.37 25.72-0.382: 18.76 32.91: OURAY REFUGE STUDY SITE                  *
 * 22 GREEN RIVER      E   399.0:       10.94 11.87: 11.37 25.72-0.382: 18.76 32.91: DUSCHESNE RIVER CONFLUENCE               *
 *----------------------------------------------------------------------------------------------------------------------------*----*
                                                                                                                              *
                                                                                                                              *
```

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                                                     NORMAL        TIME PERIOD:     SEPT                                 PAGE NO. 1
*-------------------------------------------------------------------------------------------------------------------------------*
*-----STREAM IDENTIFICATION----:---WATER TEMP.----:----EQUILIBRIUM PARAMETERS-----:
*NODE ----STREAM---- NODE STRM.:-AVG. DAILY-  MAX.:---AVG. DAILY-----:-MAX. DAILY-:
* NO.      NAME      TYPE DIST.:  OBS. PRED. PRED.:    TE    K1    K2:    TE    K1:        REMARKS
*                              :                  :       (J/M2(J/M2/:       (J/M2:                                      *
*                              :   (C)   (C)   (C):   (C) /S/C) S/C2):   (C) /S/C):                                      *
*------------------------------------------------------------------------------------------------------------------------------*-----*
*  1 GREEN RIVER      S   661.3:  9.83  9.83 11.13: 16.67 32.18-0.500: 23.19 41.26: FLAMING GORGE DAM                        *
*  2 GREEN RIVER      C   617.9:       11.87 13.78: 16.47 31.99-0.515: 23.08 41.13: LITTLE BROWN PARK                        *
*  3 GREEN RIVER      C   580.8:       13.57 15.00: 17.37 33.07-0.552: 23.13 41.25: LADORE CANYON
*  4 GREEN RIVER      C   566.4:       13.91 15.67: 16.27 31.84-0.531: 21.84 39.20: HELLS HALF MILE                          *
*  5 GREEN RIVER      B   556.7:       14.09 15.62:                  : 21.84 39.20: YAMPA RIVER CONFLUENCE                   *
*  6 YAMPA RIVER      H   681.5: 18.30 18.30 18.30: 15.96 31.26-0.573: 22.74 40.40: MAYBELL                                  *
*  7 YAMPA RIVER      S   652.0: 16.01 16.01 16.01: 16.28 31.66-0.554: 22.99 40.85: CROSS MOUNTAIN                           *
*  8 YAMPA RIVER      B   638.8:       16.14 21.78:                  : 22.99 40.85: LITTLE SNAKE CONFLUENCE                  *
*  9 LITTLE SNAKE     H   651.6: 15.62 15.62 20.34: 16.21 31.62-0.548: 22.92 40.77: LILY GAGE                                *
* 10 LITTLE SNAKE     T   638.8:       16.02 21.29:                  : 22.92 40.77: YAMPA CONFLUENCE                         *
* 11 YAMPA RIVER      J   638.8:       16.12 21.69: 16.28 31.71-0.555: 22.98 40.89: LITTLE SNAKE JUNCTION                    *
* 12 YAMPA RIVER      C   627.5:       16.13 18.99: 16.60 32.13-0.562: 23.23 41.36: LILY PARK                                *
* 13 YAMPA RIVER      C   585.7:       16.40 20.32: 16.72 32.35-0.568: 23.31 41.58: HARDING HOLE                             *
* 14 YAMPA RIVER      T   556.7:       16.53 19.65:                  : 23.31 41.58: GREEN RIVER CONFLUENCE                   *
* 15 GREEN RIVER      J   556.7:       14.42 16.17: 17.20 32.93-0.557: 23.69 42.26: YAMPA RIVER JUNCTION                     *
* 16 GREEN RIVER      C   537.4:       14.88 16.77: 16.88 32.58-0.555: 23.41 41.79: ISLAND PARK                              *
* 17 GREEN RIVER      C   526.1:       15.18 16.89: 17.79 33.69-0.579: 24.12 43.06: RAINBOW PARK                             *
* 18 GREEN RIVER      C   510.1:       15.48 17.39: 16.79 32.54-0.559: 22.88 40.96: SPLIT MOUNTAIN                           *
YEAR:
* 19 GREEN RIVER      C   502.0:       15.57 16.98: 17.13 32.95-0.568: 23.65 42.29: FLATLAND BELOW SPLIT MOUNTAIN            *
* 20 GREEN RIVER      V   485.9: 16.93 15.82 17.08: 17.13 32.95-0.571: 23.65 42.29: JENSEN GAGE                              *
* 21 GREEN RIVER      O   423.2:       16.49 17.72: 17.13 32.95-0.571: 23.65 42.29: OURAY REFUGE STUDY SITE                  *
* 22 GREEN RIVER      E   399.0:       16.65 17.86: 17.13 32.95-0.571: 23.65 42.29: DUSCHESNE RIVER CONFLUENCE               *
*------------------------------------------------------------------------------------------------------------------------------*-----*
                                                                                                                               *
                                                                                                                               *

NORMAL COMPLETION OF 'TRNSPT'.
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************************************************ TABLE IX: VALIDATION STATISTICS ************************************************
                                                                     THE PURPOSE OF THIS PROGRAM IS TO COMPUTE THE FOLLOWING STATISTICS AT EACH
VALIDATION TYPE NODE AND FOR EACH TIME PERIOD INCLUDING THE ANNUAL SUMMARY:
BEGIN VALIDATION STATISTICS FOR 'K' & 'V' NODES
         THE COEFFICIENT OF DETERMINATION (EFFECT IF BIAS REMOVED);
         THE SAMPLE CORRELATION COEFFICIENT (EFFECT IF BIAS REMOVED & PROBABLE ERROR REDUCED);
         THE MEAN ERROR (BIAS);
1.       THE PROBABLE ERROR OF PREDICTION ABOUT THE MEAN ERROR (50% CONFIDENCE LIMITS);
2.       THE MAXIMUM ERROR (RANGE);
3.       THE PROBABLE ERROR OF ESTIMATE FOR THE BIAS (50% CONFIDENCE LIMITS); AND
4.       THE NUMBER OF ERROR TERMS.
5.
6.
7.
JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
TEMPERATURE MODEL MICRO TEST SET
TFFFFFFFFFFFTFFFFFFF                                  FFFFTFFFFFFFFFFFFFFFFFTTTF
              1.      0.     12.     16.     20.     12.     11.     22.      5.
              0.      0.      0.      0.      0.      0.      0.      0.      0.
              0.      0.      0.      1.      1.      3.      1.     12.     22.
2.        0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
0.        0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
0.00      0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000    0.00  0.0000
0.00
KVRFTME.DAT     KVRFMET.DAT     dummy           KVRFSTR.DAT     KVRFSTD.DAT
0.00
KVRFHDR.DAT     KVRFHYD.DAT     KVRFSHD.DAT
GREEN RIVER        423.2   556.7
YAMPA RIVER        556.7   681.5
               3     0.0     0.0
STR. NAME #
: : :         10     0.0     0.0
STR. NAME #
** JOB CONTROL DATA **


TIME PERIOD FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET
            274.    304.      2.  .16070  .33460   0.000  0.0000   0.000  0.0000
            305.    334.      2.  .17910  .40450   0.000  0.0000   0.000  0.0000
            335.    365.      2.  .19220  .25030   0.000  0.0000   0.000  0.0000
OCT           1.     31.      2.  .19890  .18990   0.000  0.0000   0.000  0.0000
NOV          32.     59.      2.  .19890  .25390   0.000  0.0000   0.000  0.0000
DEC          60.     90.      2.  .19250  .37070   0.000  0.0000   0.000  0.0000
JAN          91.    120.      2.  .17970  .29410   0.000  0.0000   0.000  0.0000
FEB
MARCH       121.    151.      2.  .16130  .40250   0.000  0.0000   0.000  0.0000
APRIL       152.    181.      2.  .13890  .28120   0.000  0.0000   0.000  0.0000
            182.    212.      2.  .11370  .16140   0.000  0.0000   0.000  0.0000
MAY
JUNE        213.    243.      2.  .11280  .12690   0.000  0.0000   0.000  0.0000
JULY
AUGUST      244.    273.      2.  .13810  .22690   0.000  0.0000   0.000  0.0000

SEPT
** TIME PERIOD DATA **
```

```
----------------------------------------------------------------------------------------------------------------------------------
                                                  (D)    (R)    (C) (+-C)   (C) (+-C)   NO.
                NODE   STREAM     TIME  DETR.  CORR.  MEAN PROB.  MAX.  BIAS ERROR                REMARKS
                TYPE DISTANCE   PERIOD  COEF.  COEF. ERROR ERROR ERROR ERROR TERMS
----------------------------------------------------------------------------------------------------------------------------------
 STREAM
 NAME            V      485.9      OCT 0.0000 1.0000 -0.64       -1.74           2  JENSEN GAGE
GREEN RIVER
                                                                 -1.63           2
                                                                 -1.64           2
                                                                 -0.63           2
                                                          0.89    2.16           2
                                                          1.02    1.40           2
                                                          0.79    0.79           2
                                                          1.32    1.67           2
                                                          1.30    2.15           2
                                                          1.04    1.65           2
(KM)                                                             -1.59           2
                                                                 -1.84           2
                                                          0.07  0.87  2.16  0.18    24

 SUMMARY: VALIDATION TYPE NODES      OCT 0.0000 1.0000 -0.64       -1.74           2      ALL VALIDATION & CALIBRATION NODES
                                                                 -1.63           2
                                                                 -1.64           2
                                                                 -0.63           2
                                                          0.89    2.16           2
                                                          1.02    1.40           2
                                                          0.79    0.79           2
 NOV 0.9879 1.0000 -1.58                                  1.32    1.67           2
 DEC 0.7892 1.0000 -1.07                                  1.30    2.15           2
 JAN 0.0000 1.0000 -0.31                                  1.04    1.65           2
 MARCH 0.8985 1.0000
 FEB 0.0000 1.0000                                               -1.59           2
 APRIL 1.0000 1.0000                                             -1.84           2
                                                          0.07  0.87  2.16  0.18    24

 MAY 0.5976 1.0000
 JUNE 0.0000 1.0000-------------------------------------------------------------------------------------------------------------
 AUGUST 0.0000 1.0000 -0.59
 JULY 0.7299 1.0000

 ANNUAL 0.9855 0.9865
 SEPT 0.0000 1.0000 -1.32
NORMAL COMPLETION OF 'VSTATS'.
```

```
 NOV 0.9879 1.0000 -1.58
 DEC 0.7892 1.0000 -1.07
 JAN 0.0000 1.0000 -0.31
 MARCH 0.8985 1.0000
 FEB 0.0000 1.0000
 APRIL 1.0000 1.0000

 MAY 0.5976 1.0000
 JUNE 0.0000 1.0000
 AUGUST 0.0000 1.0000 -0.59
 JULY 0.7299 1.0000

 ANNUAL 0.9855 0.9865
 SEPT 0.0000 1.0000 -1.32
```

```
               JOB CONTROL FILE: UPPER COLORADO RIVER BASIN--VERIFICATION DATA SET



                                                TABLES                         T/F
                                                                                ---
TABLE 10 – Not actually labeled as such in the file.
                               STREAM GEOMETRY AFTER 'M' NODES MERGED           T
                               STREAM GEOMETRY AFTER '0' NODES MERGED           T
                               STREAM GEOMETRY AFTER HYDROLOGY NODES MERGED     T
TEMPERATURE MODEL MICRO TEST SET
                               HYDROLOGY WITH MISSING FLOWS ADDED               T
                               HYDROLOGY WITH LATERAL FLOWS ADDED               T
                               COMPOSITE-STR. GEOM., HYDR., & MET. MERGED       T
                               WATER TEMPERATURE REGRESSION STATISTICS          T
                               WATER TEMPERATURE DATA                           T
                               VALIDATION STATISTICS                            T
                               JOB CONTROL FILE                                 T
TABLE NMB.
--------- ---------------------------------------------

                                                                               -------------------------
1
2                                    C    D    E    A    J    K    M    O    P    Q    R    S    T    V
3
4                                T
5                                    T    T    T    T    T    T    T    T    T    T    T    T    T    T
6
7
VERIFICATION TABLE REQUESTS       0
8                                     0    0    0    0    0    0    0    0    0    0    0    0    0    1
---------------------------
SPATIAL OUTPUT REQUESTS
9
10

NUMBER

                                                       16          NUMBER OF COMPOSITE NETWORK NODES =   0

NUMBER OF SKELETON SUBNETWORK NODES (H,B,T,J,S,E) =
                                                          20       NUMBER OF NODES REQUIRING REGRESSION ANALYSIS =   0
NUMBER OF STREAM GEOMETRY SUBNETWORK NODES (H,J,S,C) =
                                                        12         NUMBER OF STUDY SUBNETWORK NODES (H,B,T,J,S,E,O) =  11
NUMBER OF HYDROLOGY SUBNETWORK NODES (Q,D,P,R,V,K) =
------------------------------------------------

B------------------------------------------------------------------------



-------------------------------------------------------------------------


NODE INFORMATION

NETWORK NODES
```

```
                                                    T/F

                                                     T

 MISC. CONTROL FLAGS
 --------------------                                T

                                                     T
HYDROLOGY WARNING MESSAGE
 SUPPRESSION FLAG                                    T
 REGRESSION NEED FLAG

 SHADE DATA AVAILABLE

 GLOBAL SHADE MODE

                                                                 2          FIRST YEAR OF HISTORICAL DATA=   0

                                                                1

                                                                       1     LAST YEAR SEQUENCE NUMBER OF OUTPUT =   3
NUMBER OF YEARS OF HISTORICAL DATA =
 NUMBER OF YEARS OF SYNTHETIC DATA =

 STARTING YEAR SEQUENCE NUMBER OF OUTPUT =
                                                                           1    LAST TIME PERIOD SEQUENCE NUMBER OF OUTPUT =  12

                                                                   0       LAST TIME PERIOD SEQUENCE NUMBER FOR =    0
                                                                                AIR TEMPERATURE CORRECTION

                                                             12
FIRST TIME PERIOD SEQUENCE NUMBER OF OUTPUT =
 STARTING TIME PERIOD SEQUENCE NUMBER =

 FOR AIR TEMPERATURE CORRECTION
 TEMPORAL INFORMATION
 --------------------    0.0000 (-)
 NUMBER OF TIME PERIODS PER YEAR =

 USER SUPPLIED EVAPORATION FACTORS
                         0.0000 (1/MPS)
 ---------------------------------
                         0.0000 (1/SQ.RT.(MPS))


YEARLY
 ------
EFA =
                                0.0000 (-)
 EFB =

 EFC =
 USER SUPPLIED BOWEN RATIO
 BY TIME PERIOD
 -------------------------

 --------------
BOWEN RATIO=
```

```
 GLOBAL CALIBRATION PARAMETERS
 ---------------------------------------------------------

 AIR TEMPERATURE CALIBRATION CONSTANT =            0.000 (C)
 AIR TEMPERATURE CALIBRATION COEFFICIENT =        0.0000 (-)
 WIND SPEED CALIBRATION CONSTANT =                 0.000 (MPS)
 WIND SPEED CALIBRATION COEFFICIENT =             0.0000 (-)
 HUMIDITY CALIBRATION CONSTANT =                   0.000 (DEC. OF RH)
 HUMIDITY CALIBRATION COEFFICIENT =               0.0000 (-)
 SUNSHINE CALIBRATION CONSTANT =                   0.000 (DEC. OF S/SO)
 SUNSHINE CALIBRATION COEFFICIENT =               0.0000 (-)
 SOLAR CALIBRATION CONSTANT =                      0.000 (J/SQ*M/S)
 SOLAR CALIBRATION COEFFICIENT =                  0.0000 (-)


 AIR TEMPERATURE CORRECTION FACTORS
 ----------------------------------

 1ST ELEVATION =        0.000 (M)
 1ST FACTOR =          0.0000 (C/M)
 2ND ELEVATION =        0.000 (M)
 2ND FACTOR =          0.0000 (C/M)
 3RD ELEVATION =        0.000 (M)
 3RD FACTOR =          0.0000 (C/M)
 4TH ELEVATION =        0.000 (M)
 4TH FACTOR =          0.0000 (C/M)
 5TH ELEVATION =        0.000 (M)
 5TH FACTOR =          0.0000 (C/M)
```

```
                                              0.000 (C)

                                             0.0000 (C PER HSX)

                                              0.000 (C PER RH)

                                             0.0000 (C PER S/SO)

                                             FROM (KM)    TO (KM)
 AIR TEMPERATURE REGRESSION COEFFICIENTS     --------     --------
 ----------------------------------------
                                              423.2        556.7

                                              556.7        681.5

                                          3     0.0          0.0
 MAXIMUM DAILY
                                          4     0.0          0.0

 STREAM SPACIAL OUTPUT REQUEST
                                          5     0.0          0.0
A0 =
                                          6     0.0          0.0
 ------------------
 A1 =
                                          7     0.0          0.0
GREEN RIVER
 NAME
 A2 =
 YAMPA RIVER                              8     0.0          0.0
 A3 =
                                          9     0.0          0.0
 STR. NAME #

                                         10     0.0          0.0
 STR. NAME #

 STR. NAME #

 STR. NAME #

 STR. NAME #

 STR. NAME #

 STR. NAME #

 STR. NAME #
```

```
                                                                 NAMES
                                                                 -----

                                                                 KVRFTME.DAT

                                                                 KVRFMET.DAT

                                                                 dummy

                                                                 KVRFSTR.DAT

                                                                 KVRFSTD.DAT
                STREAM NETWORK FILES
                --------------------                             KVRFHDR.DAT

                                                                 KVRFHYD.DAT

                                                                 KVRFSHD.DAT


               TIME PERIOD
                SKELETON NETWORK
                METEOROLOGY

                STREAM GEOMETRY



                HYDROLOGY DATA

                HYDROLOGY NODE
                STUDY




                SHADE
```

RULES OF THUMB

> "One shining quality lends a lustre to another, or hides some glaring defect."
>
> **-** William Hazlitt

Typically, you will use only the last table produced by a particular program unless you are debugging.

SUGGESTED READINGS FOR TOPIC 20

Look over the tables to see what they contain and how they are organized.

REVIEW QUESTIONS FOR TOPIC 20

No specific questions.

TOPIC #21: GOT THE RUNS?: YOUR FIRST RUN OF SNTEMP

Time: 1.5 hours
Format: Hands-On Small Group Exercise/Discussion
Assignment: Using the same small groups of 3-5 people carry out Exercise 21.1
Objectives: (1) Know how to execute TDATCHK and understand any errors identified.
(2) Know how to fix common errors in input data files.
(3) Know how to execute SNTEMP and interpret its run-time, on-screen output.
(4) Know how to examine SNTEMP's output files for errors.
(5) Know how to interpret SNTEMP's goodness-of-fit statistics in Table 7 and understand their limitations.

We do not have time in a classroom setting to have students assemble a complete data set. If you are using this material as a self-study guide, you presumably will be constructing your own data set, so you will get all the experience necessary. Data set assembly may be a trying experience the first time. There are many efficiencies that may be learned through time to reduce the time and potential for creating errors.

For learning purposes, you have been given a data set seeded with simple errors that the first time modeler might reasonably encounter. Please note that some errors may be far more subtle and difficult to track down, but persistence will pay off. Error messages from SNTEMP run the gamut from clear and precisely worded, to obfuscating and misleading to the point of chasing wild geese. Don't give up!

Exercise 21.1

Your assignment is a long one: (1) skim the following documentation on the **TDATCHK** program and run it on the test data set supplied (**JOBCON.BAD**); (2) correct any errors you may find; (3) run SNTEMP on the corrected data set; (4) skim SNTEMP's output files looking for obvious data errors not caught by TDATCHK; (5) review your notes on missing data and examine the goodness-of-fit statistics for the missing water temperature data in **Table 7**; and, of course, (6) understand everything that you have done.

Remember to execute your IF312 batch file to get started if you have set yourself up that way.

TEMPERATURE MODEL TECHNICAL NOTE # 7
THE PROGRAM TDATCHK - VERSION 3.1
CHECKS NETWORK TEMPERATURE INPUT DATA FILES
SEPTEMBER 1996

by
John Bartholow

TDATCHK is an aid in overcoming problems in data files such as lines being out of order, having a letter where a number should be, and illogical data values in specific fields.

Typing TDATCHK will prompt you for the job control file name. The rest should be fairly straight forward. Try it; you'll like it.

One change from Information Paper 16: Enter the number of Shade Data File nodes on line 4, columns 33-40 of the Job Control File.

Version 1.1 adds more field value checking, looking for tabs, and more explanatory messages. Version 3.0 adds several new options and data checks. First, output can be directed to a file by adding the output file name to the TDATCHK command line. For example:

```
TDATCHK kvrfjob.dat kvrfchk.out
```

where *kvrfjob.dat* is the data set job control file
kvrfchk.out is the error report file (optional)

The program now (Version 3) checks for the following error types:

Unnecessary blank lines
Node misspelling within and between files
Missing and/or extra nodes
Node collocation other than **B, T**, and **J** nodes
Time period mismatches

NOTE: Node collocation warnings are provided even though not all collocations cause errors in SNTEMP. Use this information accordingly.

The general strategy for using TDATCHK is (1) eliminate any problems with file names, i.e., problem opening xx file; (2) scan individual files and eliminate any errors on a file-by-file basis; then, and only then, run the cross comparison test (option 9). If you try to do everything at once, the error messages may get overwhelming.

RULES OF THUMB

> "A poet can survive everything but a misprint." - Oscar Wilde

ALWAYS run TDATCHK before SNTEMP!

SUGGESTED READINGS FOR TOPIC 21

Look in your directory to see if the documentation for TDATCHK may have changed from what is given in these notes. Do that for all the utilities that will be covered here.

ANSWERS FOR EXERCISE 21.1

You should have found several errors in the BAD data set (about one per each of the 7 files) and corrected them fairly easily using DOS's **EDIT** program, though it might have taken several iterations. The specific errors were:

job file	study and shade file names were wrong
hydrology node file	an 'o' was typed instead of a zero
hydrology data file	nothing substantive
meteorology data file	column shift problem
shade data file	2nd line (blank) was missing last node need not be there at all
study file	lower case o instead of O for node designator
stream geometry file	OK
Time period file	Averaging period should be 1 day if your computer is fast enough

Subsequent running in SNTEMP should have been successful, though you would have to turn on Table 7 either with the editor or through the job control update program.

TOPIC #22: GLOBAL WARMING?:
HOW TO APPROACH SNTEMP CALIBRATION
THROUGH SENSITIVITY AND ERROR ANALYSIS

Time:	2 hours
Format:	Hands-On Small Group Exercise/Discussion
Assignment:	SNTEMP Exercises 22.1 through 22.5 (some optional) As time permits, other exercises as well.
Objectives:	(1) Understand and apply general formulation of global calibration functions. (2) Evaluate results from multiple global calibration parameters. (3) Understand how model errors can be correlated with errors or biases in input data using the TEXERR program. (4) Understand how to choose a course of action in calibrating SNTEMP.

IF 312 - Exercise 22.1: Calibration and Sensitivity Training

Recall that the job control file contains the parameters to control several kinds of calibration factors. There are five **global calibration factors**: *air temperature, wind speed, humidity, sunshine,* and *solar radiation.* In addition, there are three parameters related to evaporation, the Bowen Ratio, four for maximum air temperature regression coefficients, and a set of factors that govern air temperature lapse rates by elevation zone.

In a classroom setting, the group is divided into five teams. Each team is assigned a single parameter from the Global calibration parameters (see IP #16, p. III-80) to evaluate for possible bias of the central weather stations records, this time for a real data set (**KVRFJOB.DAT**).

Perform the following steps:

1. Use **TDATCHK** to check your data set, just to get in the habit.

2. Review the formula that SNTEMP uses for these global calibration adjustments. You should be able to find it in either IP#16 or your class notes. Make a run with the Global calibration coefficient (NOT the constant) for your parameter set at 1.05, i.e., a 5% increase. [Make sure that the global shade flags are set the same as for the output files you have listed in your notebook so that legitimate comparisons can be made with the “benchmark” data set, i.e., a coefficient of 1.0.]

3. Make a run with the same coefficient set at 0.95, i.e., a 5% decrease.

4. Make other runs if you think they are appropriate.

5. Read the material on the meaning of the calibration statistics in Information Paper 16 pages II-81 and 82, Information Paper 13 pages 89-96, and at the top of SNTEMP’s output Table 9.

Also refer to Figure 22.1 below that shows how minimizing the errors and maximizing the r-value both must be considered in “tuning” the model.

6. Plot the Annual mean error from **Table 9** for these two runs and the benchmark run.

7. Answer the following questions:

    a. Does there appear to be any systematic bias in the Grand Junction weather observations as determined by the mean error? If so, does the model improve if you change any global factor by a percentage, either up or down? If you can't improve the model globally, what other tacks could you take?

    b. What was the best fitting month in the benchmark? Did it get better or worse with any adjustment?

    c. Ditto for the poorest fitting month? Why do you think the poorest month was the poorest?

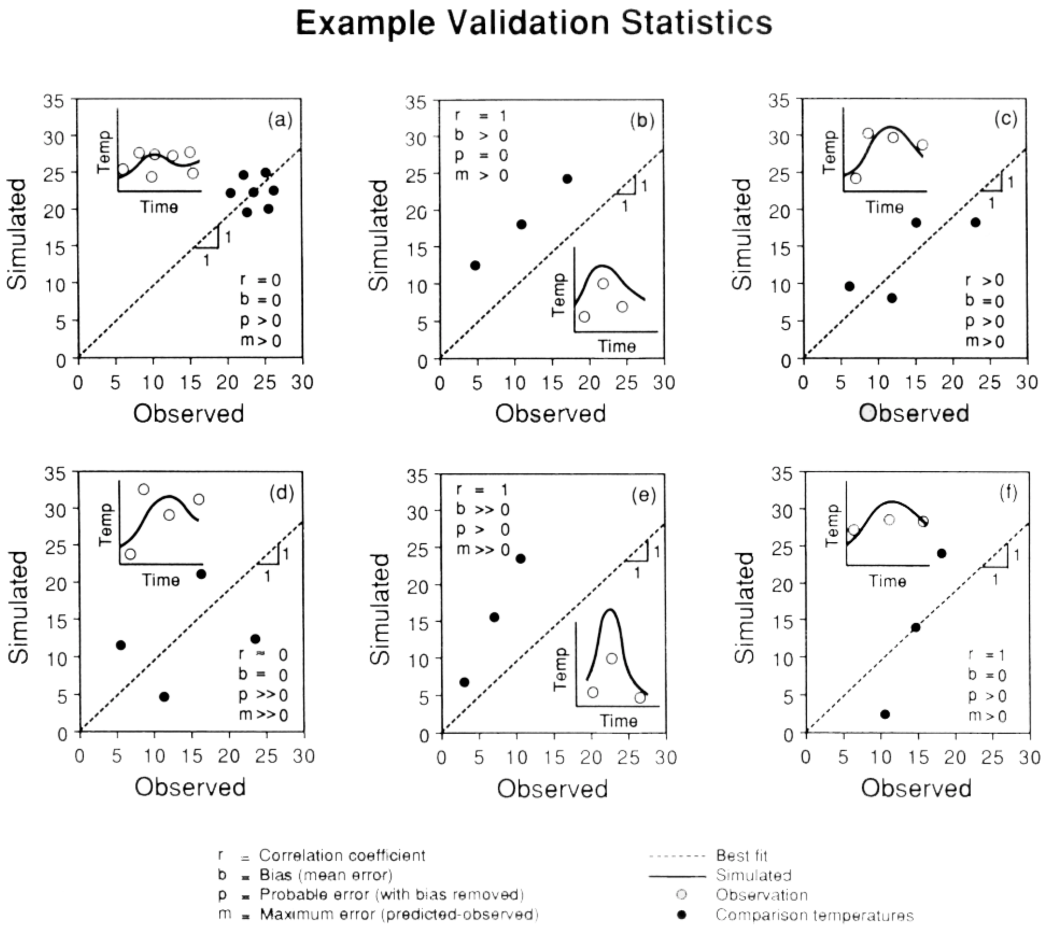
    d. What was the most sensitive parameter? Why?

    e. From what you know right now, how should you choose which parameters to alter to calibrate this model (singly or in combination), and what strategy should you use in adjusting them?

8. Report the results in-group wrap-up session. Construct a table that looks something like this:

Coefficient	0.95	1.0	1.05
Air Temperature Annual R value Mean error Probable error Maximum error Bias error			
Wind Speed Annual R value Mean error Probable error Maximum error Bias error			
Humidity Annual R value Mean error Probable error Maximum error Bias error			
Sunshine Annual R value Mean error Probable error Maximum error Bias error			
Solar Radiation Annual R value Mean error Probable error Maximum error Bias error			

Figure 22.1. Different possibilities for the relationship between simulated and observed temperatures. (A) shows no bias, but also no correlation and some dispersion error. (B) shows excellent correlation, but a high error. (C) shows good correlation and bias, but also high dispersion error. (D) has the same characteristics as A, but for different reasons. (E) shows excellent correlation, but everything else is poor. (F) shows good correlation and bias, but poor dispersion error. The goal, of course, is to maximize the correlation and minimize all error components.



IF 312 - Exercise 22.2: Error Analysis

The last exercise should have gotten you thinking about systematic model errors. Some of these errors we can catch, some are elusive. Though it has not proven generally useful, it is nice to identify and eliminate any systematic biases that may exist in a more structured way. **EXERR** is one way to do this.

Read the documentation for EXERR below and run it for your best data set from the previous exercise. Identify if any parameters are significant and warrant further attention.

TEMPERATURE MODEL TECHNICAL NOTE #8

PROGRAM EXERR - VERSION 2.4

NOVEMBER 1992

EXAMINE SNTEMP MODEL ERROR FOR CORRELATIONS

SUMMARY

Program EXERR is an automated method of examining the temperature model's error (simulated mean daily temperature minus observed temperature). Correlations are performed for all meteorological parameters, time, flow, and distance. A standard Pearson correlation is used, and as with any correlation, there must be at least three observations. A flag in the output file serves to highlight significant correlations warranting further attention. Even if not flagged, high correlations can offer clues for what further calibration may have the highest payoff.

Error estimates are taken from the KVRSTAT output file from SNTEMP, one per time period. The corresponding values for each parameter are taken from the SNTEMP input files, and averaged for each time period where needed. The flow values are taken from the hydraulic data set, and are averaged by time period over all years, and then averaged again over all V nodes for the summary of validation nodes.

INPUT FILES

A job control file, a KVRSTAT output file (Table 9), a meteorological data file, a hydraulic data file, and a time period file.

OUTPUT FILES

A file that contains the correlation results - ZOUT by default.

EXECUTION PROCEDURE

To run EXERR type:

```
TEXERR TJOB ZOUT KVRSTAT
```

where: JOBCON = Job control file (input)
ZOUT = File containing correlation results flags (output)
KVRSTAT = KVRSTAT output file - Table 9 (input)

The names for the meteorological data file, hydrology node file, and time period file will be read from the job control file and must be present in the directory you are running.

ERROR MESSAGES

1. ERROR IN MODEL INPUT FILE

   An error has occurred while reading the JOBCON file.

2. ERROR IN HYDROLOGY FILE, REVIEW YOUR DATA
3. UNABLE TO OPEN JOB CONTROL FILE
4. UNABLE TO OPEN MODEL INPUT FILE
5. UNABLE TO OPEN OUTPUT FILE
6. UNABLE TO OPEN TIME FILE
7. UNABLE TO OPEN METEOROLOGY FILE
8. UNEXPECTED END OF FILE IN JOB CONTROL FILE
9. UNEXPECTED END OF FILE IN METEOROLOGY FILE
10. UNEXPECTED END OF FILE IN KVRSTAT
11. UNABLE TO OPEN SCRATCH FILES
12. UNABLE TO CLOSE SCRATCH FILES
13. UNEXPECTED END OF FILE IN TIME FILE
14. UNABLE TO OPEN HYDROLOGY DATA FILE
15. NORMAL END OF EXERR
16. **ERROR - INCORRECT NUMBER OF V NODES ON HYDROLOGY DATA FILE, REVIEW YOUR DATA.

LIMITATIONS

EXERR is incomplete in that there are several other parameters that could be examined, such as width, model-calculated solar radiation, shade -- basically any dynamic factor.

IF 312 - Exercise 22.3: Application to a Problem

The verification data set you are working with (**KVRFJOB.DAT**) covers part of the geographical spawning range of an endangered species, the Colorado River Squawfish, now called a pike minnow I believe. For the purposes of the exercise, the following facts are given:

A. The Colorado Squawfish spawns in June and/or July on the falling limb of the spring melt hydrograph.

B. The water temperatures must be above 20°C for at least two weeks for the squawfish to spawn.

C. The water temperatures must be above 18°C for emerged squawfish fry to survive as they are washed downstream.

D. It appears that a sudden crossing of either of these temperature thresholds causes spawning to fail or the fry to die in large numbers.

Directions:

1. By looking at the results of the runs you have been making, develop a working hypothesis about what is likely to happen in this study area at for the Yampa and Green Rivers.

2. Model Runs

    a. Use whichever data set you prefer based on calibration exercise.

    b. Set the Job Control File to obtain 3 years of output (begin in year 1 and end in year 3).

    c. Set the Job Control File to request **Table 8** only (you do not need the other tables for this exercise; do you know why?).

    d. Do anything else in your model setup that you feel necessary to solve this problem.

3. Use the model to address the following questions:

    a. What release temperature at Flaming Gorge Dam would be required to maintain 20°C at the Ouray Refuge site below Jensen through the end of September? Is this feasible? How do you know?

    b. Can we provide for fry drifting down the Yampa River by managing the release temperature at Flaming Gorge? What information would the operators need? How could you use this model to provide it?

    c. What about managing discharge instead of, or in addition to, release temperature?

4. Provide a thumbnail report for the class from your group. The report will include at least:

    a. A problem summary

    b. Exactly what question you were trying to answer

    c. What steps you took

    d. What problems you encountered

    e. What results you found

IF 312 - Exercise 22.4:Model Comparison (optional)

a. Compare performance of SSTEMP with SNTEMP

b. Concentrate lateral flow at upstream, downstream, or make it uniformly distributed.

IF 312 - Exercise 22.5: Data Entry Set-up (optional)

Enter a set of data files for a sample problem you either make up or have brought with you. This can be for either the stream reach model or stream network model.

RULES OF THUMB

"Get your facts first, and then you can distort them as much as you like." – Mark Twain

"To treat your facts with imagination is one thing, but to imagine your facts is another."
- John Burroughs

Adjustment of input data to calibrate the model is legitimate within bounds. All data has biases, but so does the model. Removing data biases is what you want to do. However, it is possible to start to "over correct" the input data. My advice is to only adjust the input data if there is a strong rationale to do so.

Goodness of fit statistics comparing model output with measured temperatures at verification nodes are found in Table IX. Goodness measures may include all or some following criteria.

1. Mean Error - The mean of the absolute values of the simulated temperatures, minus the mean of the observed temperatures over all time steps and all geographic locations should be # 0.5°C.
2. Dispersion Error - No more than 10% of the simulated temperatures should be more than 1°C from the measured temperatures.
3. Maximum Error - No single simulated temperature should be more that 1.5°C from the measured temperatures.
4. There should be no trend in spatial, temporal, or prediction error.

Note that the dispersion error and maximum error may be used in developing a conservative recommendation. That is, if the dispersion error were 1.5°C, you may wish to err on the conservative side by that amount. It should also be apparent from this discussion that large calibration errors are not necessarily grounds for discarding the model results. The first course of action should be to improve model accuracy, if the source(s) of error can be identified. If the accuracy cannot be improved, then a conservative treatment of the results, described above, is warranted.

SUGGESTED READINGS FOR TOPIC 22

None.

REVIEW QUESTIONS FOR TOPIC 22

No specific questions.

TOPIC #23: DIGESTION OF RESULTS

Time: 1-2 hours
Format: Homework
Assignment: (1) Review today’s activities and sort out as many questions as you can.
(2) Be prepared to ask questions tomorrow.
Objectives: (1) Internalize elements of calibration, model evaluation through goodness-of-fit statistics, and utility programs.
(2) Be exposed to the most basic utility of SNTEMP.

You have been dealing with the tedious details of running SNTEMP. Let's pause for a moment and reflect on what was covered yesterday.

REVIEW QUESTIONS FOR TOPIC 23

Considering what you know about heat flux (referring to whatever diagrams seems relevant), explain the relationship between the following stream geometry data elements and heat flux: latitude, elevation, Manning’s n, width, shade, azimuth, ground temperature, and thermal gradient. Which, if any, of these factors may fit into a calibration scheme?

ANSWERS FOR TOPIC 23

(1) Latitude - determines, in part, solar radiation intensity, sunrise and sunset.
(2) Elevation - determines, in part, air temperature, humidity, and air pressure adjustments from weather station elevation to site.
(3) Manning’s n - determines fluid friction, travel time, and maximum temperatures.
(4) Width - determines, in part, direct long and short wave radiation available to the water mass.
(5) Shade - determines, in part, radiation entering water.
(6) Ground temperature - determines lateral inflow (groundwater) temperature unless overridden.
(7) Stream bed thermal gradient - determines conduction/insulation between stream and ground.
(8) Azimuth - in shade model gives percent of surface exposed at any time considering topographic and vegetative shading relative to orientation of stream and sun.

Potentially any may fit into a calibration scheme, but some (like latitude and elevation) should be relatively precisely known and should not be tinkered with. Others, like Manning's n, width, and shade, may be much more appropriate for adjustment, though they may not all be sensitive depending on the circumstances.

TOPIC #24: QUESTIONS FROM DAY 3

Time: 0.25 hours
Format: Discussion
Assignment: Be prepared to ask for clarification.
Objectives: Clarity, perspective, and understanding.

After the third full day, covering Topics 17-23, students are generally starting to see the light. Nonetheless, the trees may still be obscuring the forest at this time. No one is ever quite sure how he or she would tackle calibrating the SNTEMP model, as it appears that there are so many seemingly unrelated parameters, both global and temporal. In addition to covering this subject, it is a good idea to press students for questions about how they would use the model in their work, or something to ground them in the practical utility of the models. As before, the question/answer session is meant to be free roaming. Always emphasize that no question is too silly or absurd. If someone has a question, it is a safe bet that someone else wants to ask that question too.

If you are taking the self-study class, take a moment and e-mail any questions to the instructor.

TOPIC #25: FIELD DATA COLLECTION: PRACTICE AND PROBLEMS

Time:	1.5 hours
Format:	Lecture/Reading
Assignment:	Review notebook material
Objectives:	(1) Know which data may be gathered from existing sources and which typically need to be gathered from the field. (2) Know about various equipment for data collection, including thermographs and meteorological stations, photo-gray cards, clinometers, and dye studies. (3) Understand key cost-efficient considerations in field data collection. (4) Understand types of field problems commonly encountered and learn strategies for dealing with them. (5) Know how to estimate parameters for which data cannot be collected.

Much of the material for this topic is adequately covered in Information Paper 13, which you should review. Presented here are some new ideas as well as material well worth reinforcement.

Field Data Collection and Considerations

Thermographs. Probably the first piece of equipment that comes to mind when discussing water temperature data collection is the thermograph. Much improved from the "old days," the newer electronic instruments are now fairly reliable, accurate, and sophisticated, yet far from fool proof. Probably the best known of contemporary thermographs is the Ryan. Though I suspect that there are far more Ryan's in meat and produce trucks around the country, there are a lot scattered throughout the streams of this nation.

Ryan's are reasonably rugged, can be purchased with a variety of add-ons, and expensive. I wish I could say that they are as rugged as they should be. I, and others, have had them "turn off" unexpectedly in the bouncing around they get in shipping and handling. They require cabling to computer software that is not as flexible as one might wish for a $500 item. But you can easily get a variety of waterproof or water resistant cases, thermistor probes on about any length cable you might want, and they offer one thing that most other thermographs do not -- direct and immediate readout of temperature. That way, you know for sure that your equipment is working and you can use to probe deep holes in the river if you wish.

Fast gaining on Ryan, largely due to cost, is the Hobotemp, Stowaway, and Tidbit loggers by Onset. These guys cost between $50 and $150 each and require no cabling. However, they have no direct readout. They also require a $200 coupling device. These instruments came out after Information Paper 13. You can contact Onset at 508-563-9000 or http://www.onsetcomp.com. See Table 25.1 for more on these units.

Table 25.1. Onset model comparison. Product information is as of July, 1998.

Feature/Model	Stowaway	Tidbit	Hobo
Cost	$130 to $190	$100	$50
Other needs	Completely sealed Optional Optic Shuttle ($200)	Completely sealed Optional Optic Shuttle ($200)	Waterproof case ($20) required, with o-ring and lubricant
Sampling Frequency (depending on memory purchased)	0.5 sec - 4 hr 48 min, most are awkward intervals	0.5 sec - 4 hr 48 min, most are awkward intervals	0.5 sec - 4 hr 48 min, most are awkward intervals
Sampling Duration	4 hr 31 min – 6504 days	1 hr 6 min - 1588 days	15 min - 360 days
Battery	10 year factory replaceable	5 year, non replaceable	Two year user replaceable
Sampling Features	Instantaneous, or average, minimum, maximum, and out of range	Instantaneous, or average, minimum, maximum, and out of range	Instantaneous only
Confirmation	Blinks while recording, stops when full, also shows out of range and waiting for trigger	Blinks while recording, stops when full, also shows out of range and waiting for trigger	Blinks while recording
Measurement Format	C or F	C or F	C or F
Measurement Range	-5 to 37° C	-5 to 37° C	-20 to 70° C
Accuracy, nominal	~0.2° C	~ 0.2° C	~ 0.7° C
Precision, readout	0.01° C	0.01° C	0.1° C
Response time in water, nominal	2 minutes	1 minute	25 minutes
Legend Flexibility	40 characters in addition to serial number	40 characters in addition to serial number	40 characters in addition to serial number
AFull≅ performance	Wrap or stop – nice	Wrap or stop - nice	Wrap or stop - nice

Delayed start	Programmable – nice	Programmable - nice	No
Triggered start	Yes – nice	Yes - nice	No
Field Downloadable	To extra cost Optic Shuttle; this starts immediate relaunch	To extra cost Optic Shuttle; this starts immediate relaunch	Has its own $160 "shuttle"
Other	Not buoyant Dark color - hard to see in water Requires cleaning	Not buoyant Has bright yellow for easier underwater location Requires cleaning Really small (including serial numbers) Requires the logger's small "bail" (hole), usually used to attach it to something, be clear to launch or download, i.e., you have to completely unhook it.	Buoyant, and large, so can be subject to washout at higher flows Can be upgraded to record four channels

Omnidata's Datapods, or a company with like products, may prove useful if you want to set up a met station for air temperature, relative humidity, wind speed, and solar radiation. Just be advised that these instruments require calibration and maintenance. Onset, too, has some add-ons for several of these parameters, but I have used none.

By the way, the best advice I have heard on minimizing (not eliminating) problems with vandalism is to make your equipment look like garbage. The more you try to make it invulnerable, the greater someone’s challenge in destroying it.

What follows is a thermistor deployment checklist. Use it as a starting point for your own mind-prompter before heading out to the field.

Table 25.2 Thermistor Deployment Checklist

Define objective

usually model calibration/verification, but may be something else, e.g., research

Equipment

securing material - nylon cord, weights & floats, stakes or rebar
hammer and needle-nosed pliers?
knife
thermistor "equipment" including silicone rings & grease, silica packets
portable computer and software
backup batteries?
watch
field book
auditing thermometer
waders
camera and film
maps etc.
brush removal equipment, e.g., axe, machete
spray paint, surveyors tape
GPS?
towel(s)
plastic bags

Data recording form

Name and Date
Stream and Site name, with specific location
Map name
Device, serial number
Specific Placement, including
    location,
    depth,
    channel characteristics, i.e., pool, riffle, run
    bank characteristics
    canopy
    other comments

Date launched _________ retrieved _________
Time launched ________ retrieved _________

Don't put thermistor near where curious animals (raccoons) may disturb them.
Do make them look like garbage

Thermistors have gotten increasingly accurate and low cost, so much so that deploying multiple units as insurance against loss or damage is probably a good idea. But always be on the alert for potential malfunctions. The following figures, courtesy of the Forest Science Project at Humboldt State University are instructive.

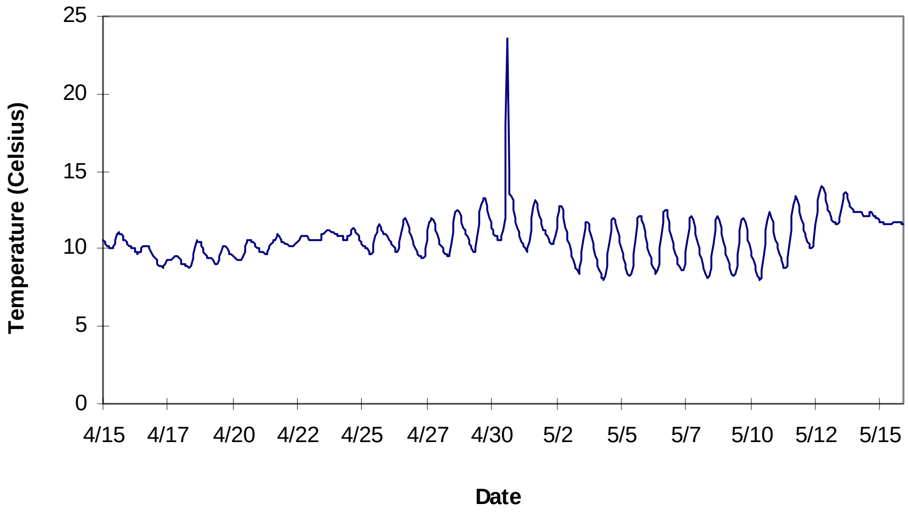


Figure 25.1. Example thermograph with an ambient air spike. In this case, the device was removed from the water to determine its operating status.

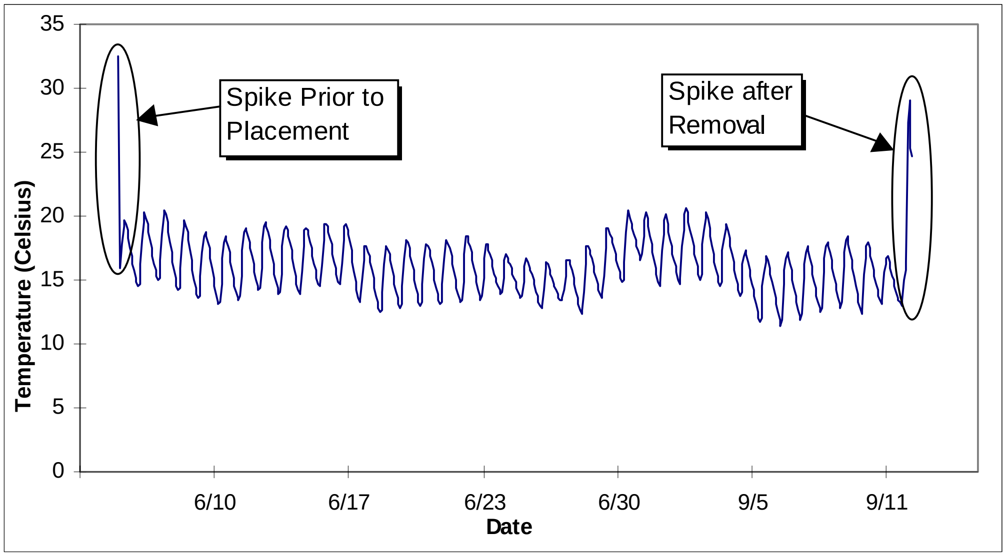


Figure 25.2. Example thermograph with air temperature spikes occurring prior to gauge placement and after gauge removal. These anomalous air spikes must be removed from the water temperature data set prior to analysis.

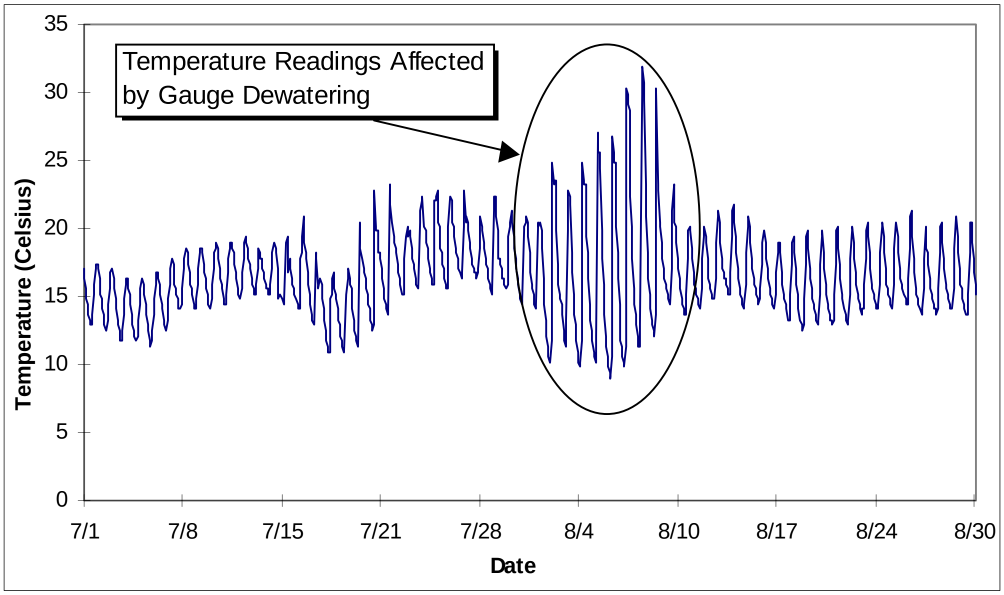


Figure 25.3. Example thermograph where the sensing device was de-watered for about ten days during the summer (August 1 to August 10).

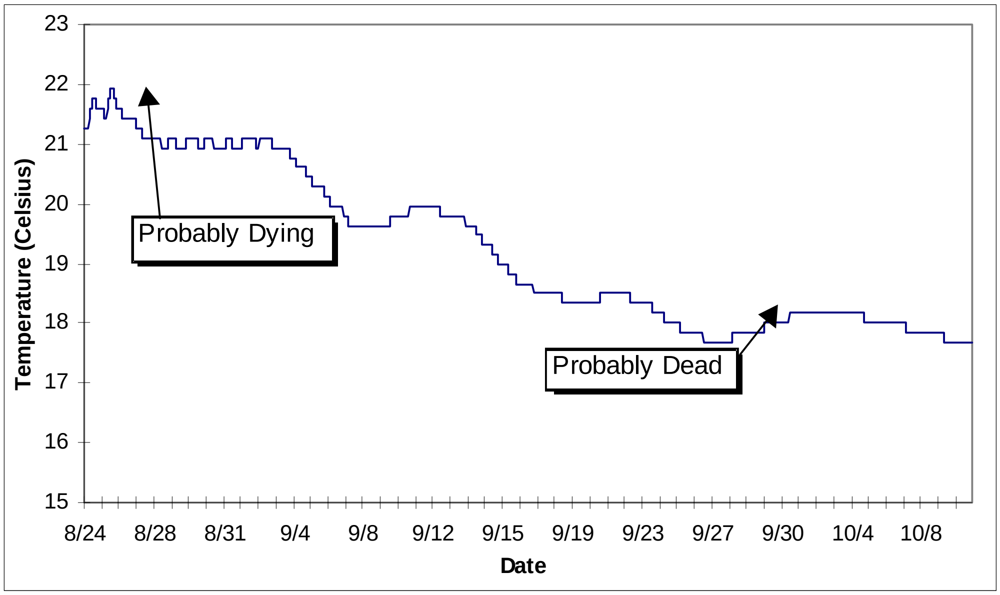


Figure 25.4. Example thermograph where the sensing device had a dying battery.

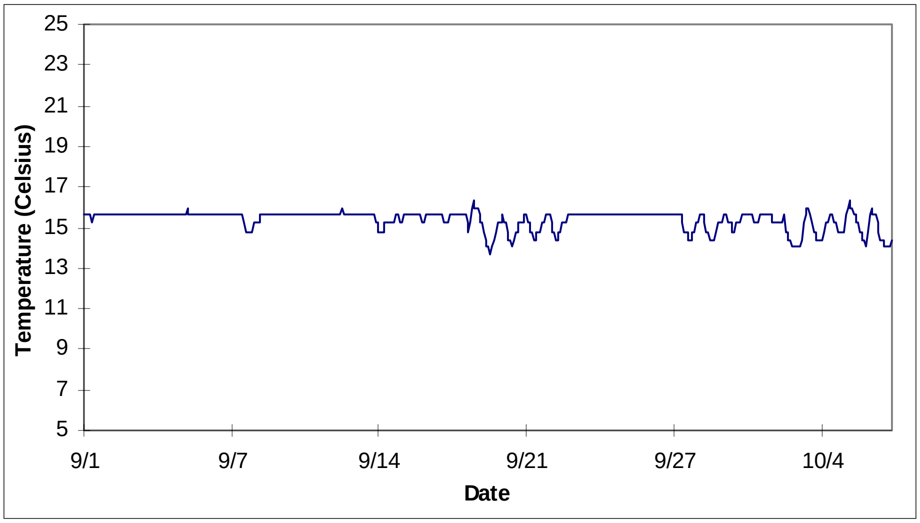


Figure 25.5. Example thermograph that exhibits behavior similar to a dying battery, but is actually a deep, thermally-stratified pool, with groundwater as the primary source of water influx.

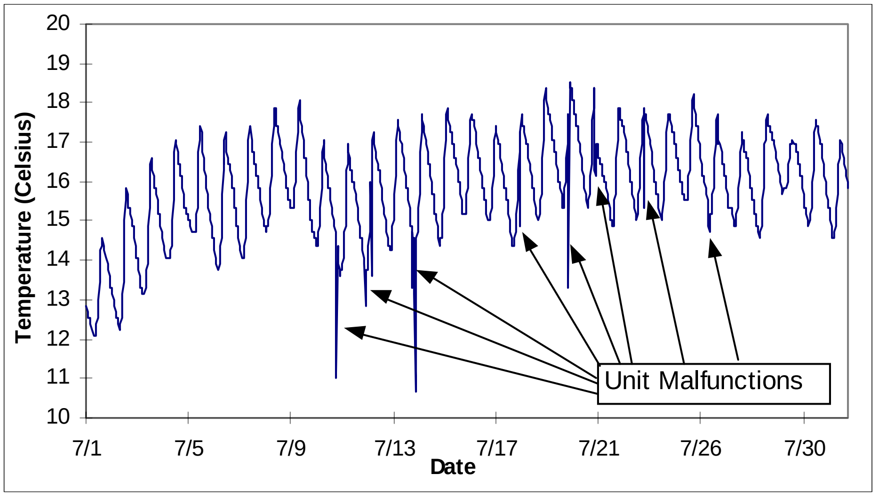


Figure 25.6. Example thermograph where the sensing device was probably malfunctioning. In this case, the device recorded significant, instantaneous down-spikes that were not water temperatures.

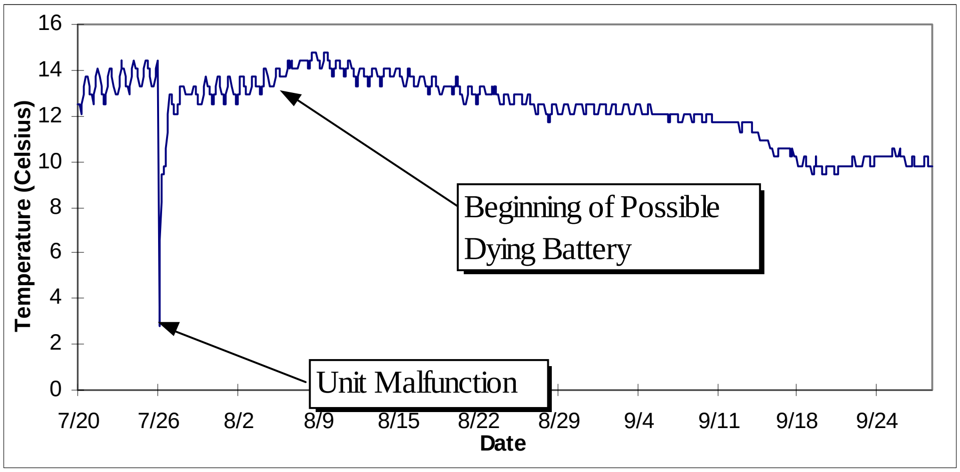


Figure 25.7. Example thermograph with a significant unit malfunction, and indications of a dying battery (but probably associated with the unit malfunction).

Equipment issues are interesting. However, the more challenging issues are ones of geographic coverage. The number of thermographs needed for a study, given human resources cost, is an element that bears some scrutiny. Not only must you struggle with the practical issues of access to the study area, but you must also not ignore your equipment for too long. With advertisements about long battery life and huge number of points being logged before service, it may become tempting to deploy the instrument and come back three months later. Three months is a lot of data to lose. Especially if you are likely to go to court, check and calibrate your instruments as often as your budget will allow, or install multiple units.

Sampling Locations for Water Temperature

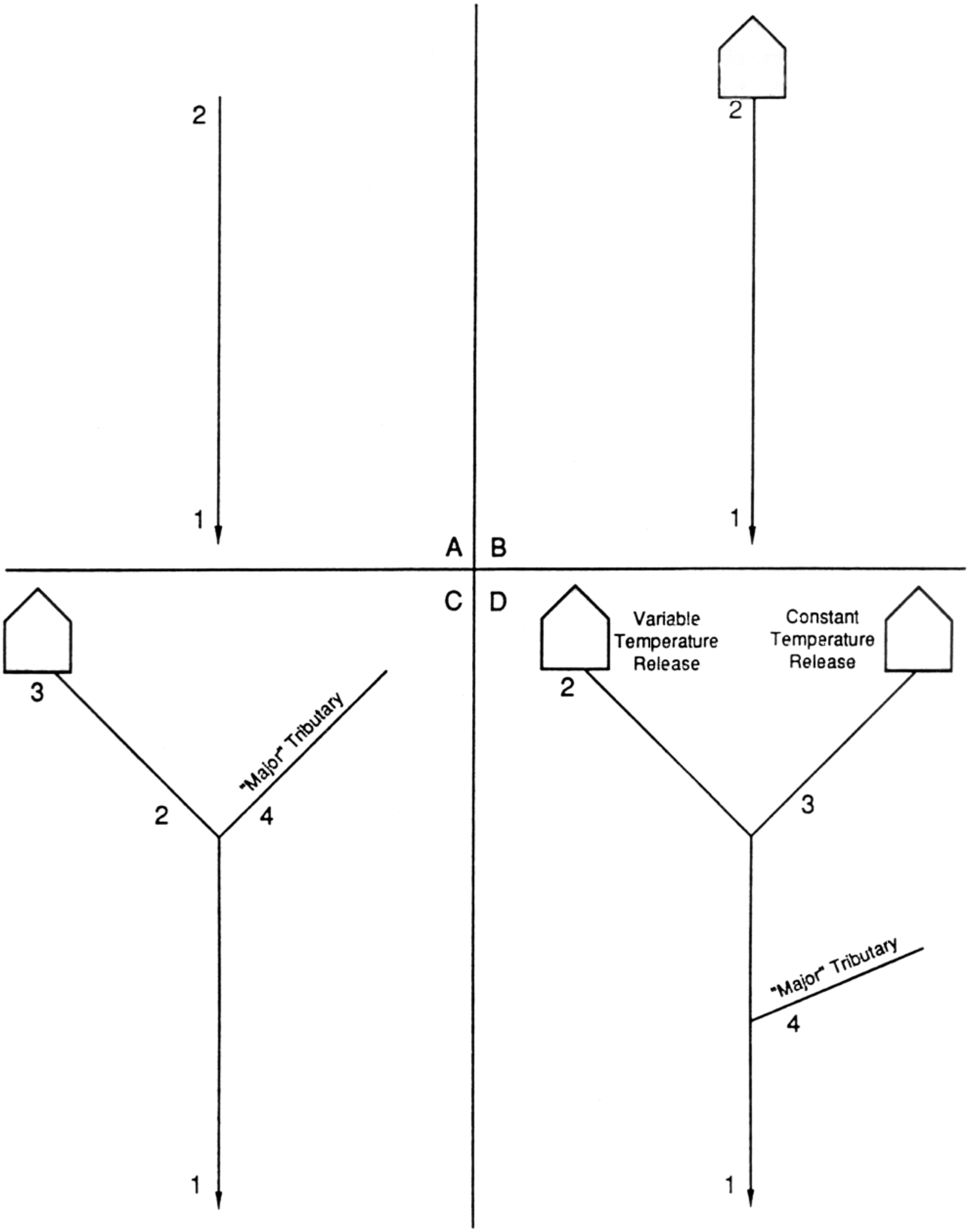
There are several considerations that factor into decisions on how many and where temperature-recording instruments should be placed. The "how many" is often based on cost. Figure 25.2 illustrates the relative priorities for establishing stations in different system configurations. Obviously, the first priority is to accurately measure stream temperatures within the river reach(es) of biological importance (Figure 25.2.a). This (single) location may also suffice for calibration purposes. Beyond this first priority, the picture becomes cloudy, with lots of intervening variables; nevertheless, we can make some generalizations. In general, the next priority must be assigned to reservoir release temperatures or other boundary conditions (Figure 25.2.b), since all temperature models require these starting water temperatures. Sometimes, if it is known that reservoir release temperatures are relatively constant, at least through the season of concern, measuring that temperature through time may not be as important. Further, as the distance from important biological sites to a reservoir becomes large (greater than 30 km), the need for release temperature measurements decreases. In such cases, using equilibrium release temperatures in the model may suffice. This is not to say that you should not measure the release temperature; however, if time, money, and labor are limiting, this may be an area where data can be sacrificed. Using the segment temperature model (SSTEMP) to test system sensitivity may be beneficial.

In a situation where there is no reservoir, headwaters are the logical candidate. It could be argued, however, that headwaters sufficiently far upstream (greater than 30 km) can just as easily be approximated by using the “zero flow headwater” approach. If there is a reservoir accompanied by one or more other “major” tributaries (Figure 25.2.c), it could be argued that knowing the upstream temperature immediately above the junction may be more important than knowing the reservoir release temperature, again considering the relative distances involved. That is, if there is no area of biological concern above the junction, we do not care as much about the temperature profile in the upper reaches. If, however, the release temperature fluctuates dramatically, or more important, release temperature is a management action to be evaluated, placing a recorder at that location should be a priority (Figure 25.8.d).

For our purposes, a “major” tributary should not be defined by the standard 10% of the mainstem flow rule, but by a temperature change definition. For example, a tributary that changes the temperature of the mainstem by more than 5% should be included. The mixing equation may be used to estimate temperature change. One must think ahead, however, for a tributary may not presently be changing mainstem temperatures, but it may do so under altered or post-project conditions.

Beyond these general rules, one can only say the more temperature locations the better; more provides insurance against inevitable downtime and lost data. A greater instrument density will also help you isolate troublesome reaches for which the models seem to perform poorly. However, more monitoring stations also add to the cost. I can think of no case in which the density of recorders needs to be greater than every 5 km along a mainstem, all other things being equal; this should be adequate for small (less than 50 cfs) streams. For larger rivers, sampling every 10-km may be adequate. Why?

Figure 25.8. Priorities for collection of water temperature data.

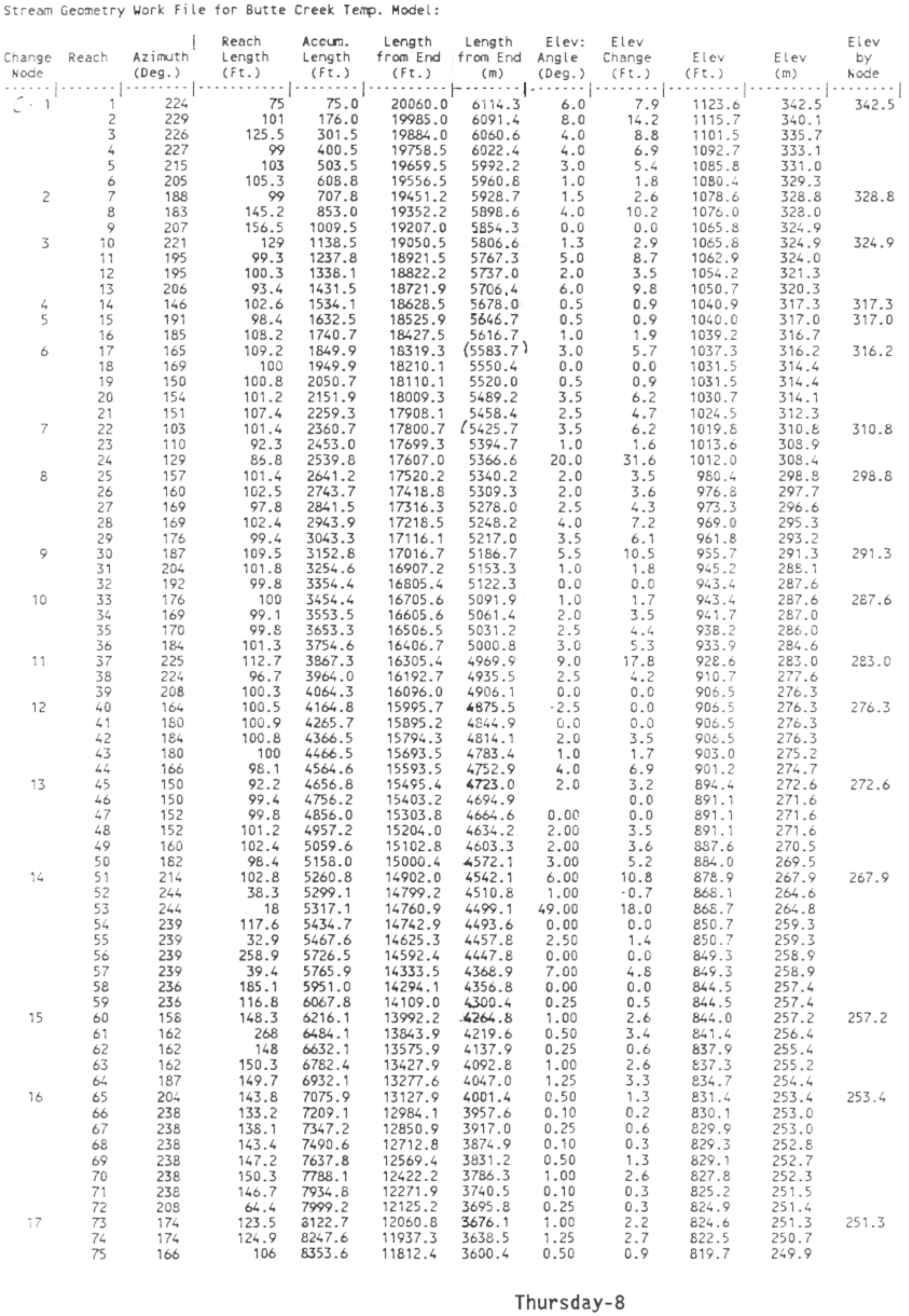


Stream Geometry and Shade Parameters

The more tedious data collection in water temperature modeling relates to stream geometry and shading. I say tedious, but it can be one of the most enjoyable components. Some people really get into this and try to measure everything in extreme detail, in precise geographic resolution. I caution you against this. I'm not arguing against good data collection, I just want you to consider that there is much inherent error in these measurements and that spending an inordinate amount of time or money may not be worth it. Do perform a sensitivity analysis and re-question yourself about the objectives. If a serious management action involves riparian vegetation management, getting detailed canopy cover data is warranted; if not, don't put in too much time. Attached is an example (Figure 25.2) of a field data form used by an individual with a penchant for detail. I must say that his models were remarkably accurate, but I think they worked out well not because of the detail. I can't prove it though.

Information Paper 13 is a good source of information about clinometers, gray cards, etc., and does not warrant being repeated here. A relative newcomer, however, is the Global Positioning System, or GPS, that may be useful in measuring on-river elevations.

Figure 25.2. Example detailed field collection notes, page 1.

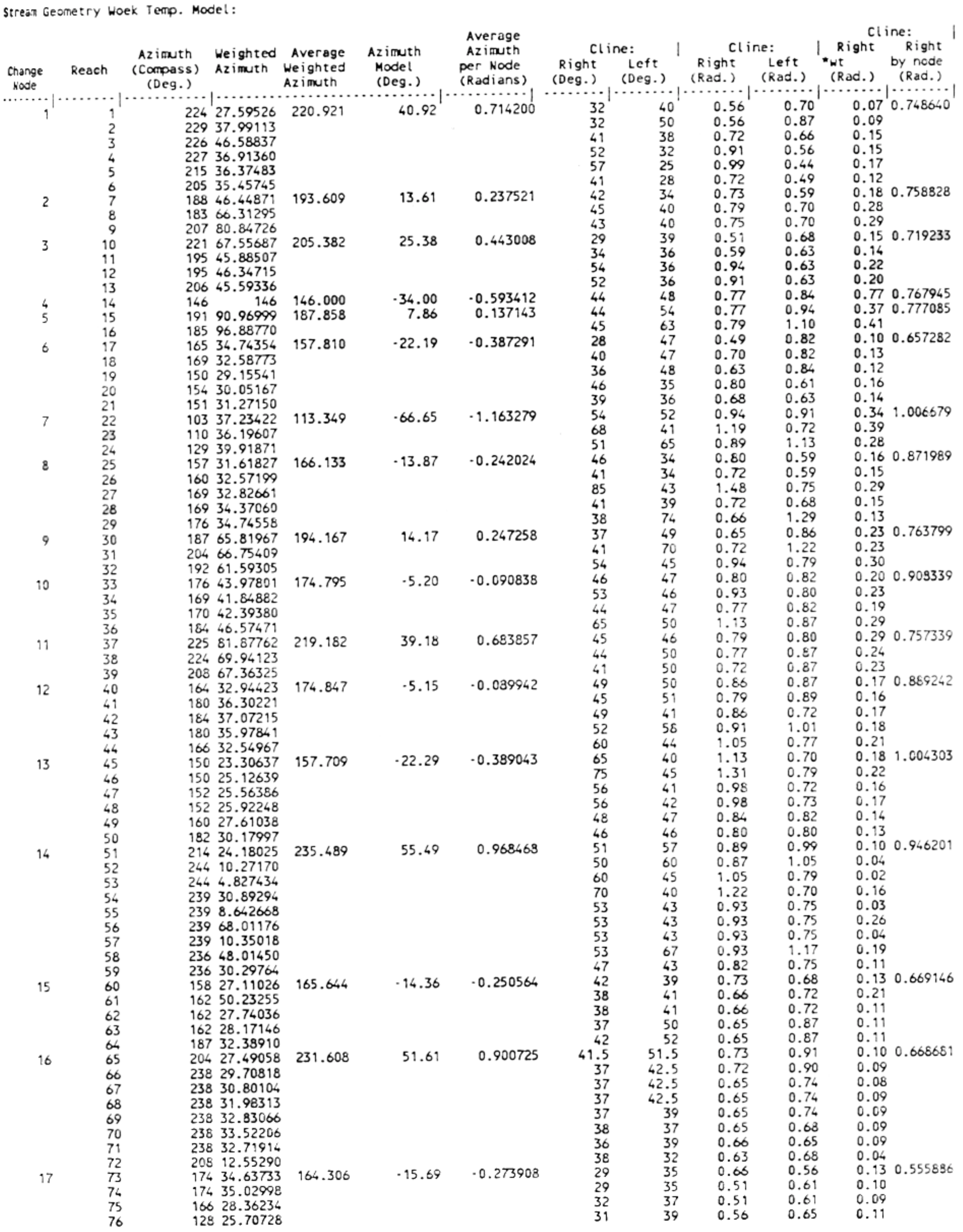


Stream Geometry Work File for Butte Creek Temp. Model:

Change Node	Reach	Azimuth (Deg.)	Reach Length (Ft.)	Accum. Length (Ft.)	Length from End (Ft.)	Length from End (m)	Elev: Angle (Deg.)	Elev Change (Ft.)	Elev (Ft.)	Elev (m)	Elev by Node
1	1	224	75	75.0	20060.0	6114.3	6.0	7.9	1123.6	342.5	342.5
	2	229	101	176.0	19985.0	6091.4	8.0	14.2	1115.7	340.1	
	3	226	125.5	301.5	19884.0	6060.6	4.0	8.8	1101.5	335.7	
	4	227	99	400.5	19758.5	6022.4	4.0	6.9	1092.7	333.1	
	5	215	103	503.5	19659.5	5992.2	3.0	5.4	1085.8	331.0	
	6	205	105.3	608.8	19556.5	5960.8	1.0	1.8	1080.4	329.3	
2	7	188	99	707.8	19451.2	5928.7	1.5	2.6	1078.6	328.8	328.8
	8	183	145.2	853.0	19352.2	5898.6	4.0	10.2	1076.0	328.0	
	9	207	156.5	1009.5	19207.0	5854.3	0.0	0.0	1065.8	324.9	
3	10	221	129	1138.5	19050.5	5806.6	1.3	2.9	1065.8	324.9	324.9
	11	195	99.3	1237.8	18921.5	5767.3	5.0	8.7	1062.9	324.0	
	12	195	100.3	1338.1	18822.2	5737.0	2.0	3.5	1054.2	321.3	
	13	206	93.4	1431.5	18721.9	5706.4	6.0	9.8	1050.7	320.3	
4	14	146	102.6	1534.1	18628.5	5678.0	0.5	0.9	1040.9	317.3	317.3
5	15	191	98.4	1632.5	18525.9	5646.7	0.5	0.9	1040.0	317.0	317.0
	16	185	108.2	1740.7	18427.5	5616.7	1.0	1.9	1039.2	316.7	
6	17	165	109.2	1849.9	18319.3	(5583.7)	3.0	5.7	1037.3	316.2	316.2
	18	169	100	1949.9	18210.1	5550.4	0.0	0.0	1031.5	314.4	
	19	150	100.8	2050.7	18110.1	5520.0	0.5	0.9	1031.5	314.4	
	20	154	101.2	2151.9	18009.3	5489.2	3.5	6.2	1030.7	314.1	
	21	151	107.4	2259.3	17908.1	5458.4	2.5	4.7	1024.5	312.3	
7	22	103	101.4	2360.7	17800.7	(5425.7	3.5	6.2	1019.8	310.8	310.8
	23	110	92.3	2453.0	17699.3	5394.7	1.0	1.6	1013.6	308.9	
	24	129	86.8	2539.8	17607.0	5366.6	20.0	31.6	1012.0	308.4	
8	25	157	101.4	2641.2	17520.2	5340.2	2.0	3.5	980.4	298.8	298.8
	26	160	102.5	2743.7	17418.8	5309.3	2.0	3.6	976.8	297.7	
	27	169	97.8	2841.5	17316.3	5278.0	2.5	4.3	973.3	296.6	
	28	169	102.4	2943.9	17218.5	5248.2	4.0	7.2	969.0	295.3	
	29	176	99.4	3043.3	17116.1	5217.0	3.5	6.1	961.8	293.2	
9	30	187	109.5	3152.8	17016.7	5186.7	5.5	10.5	955.7	291.3	291.3
	31	204	101.8	3254.6	16907.2	5153.3	1.0	1.8	945.2	288.1	
	32	192	99.8	3354.4	16805.4	5122.3	0.0	0.0	943.4	287.6	
10	33	176	100	3454.4	16705.6	5091.9	1.0	1.7	943.4	287.6	287.6
	34	169	99.1	3553.5	16605.6	5061.4	2.0	3.5	941.7	287.0	
	35	170	99.8	3653.3	16506.5	5031.2	2.5	4.4	938.2	286.0	
	36	184	101.3	3754.6	16406.7	5000.8	3.0	5.3	933.9	284.6	
11	37	225	112.7	3867.3	16305.4	4969.9	9.0	17.8	928.6	283.0	283.0
	38	224	96.7	3964.0	16192.7	4935.5	2.5	4.2	910.7	277.6	
	39	208	100.3	4064.3	16096.0	4906.1	0.0	0.0	906.5	276.3	
12	40	164	100.5	4164.8	15995.7	4875.5	-2.5	0.0	906.5	276.3	276.3
	41	180	100.9	4265.7	15895.2	4844.9	0.0	0.0	906.5	276.3	
	42	184	100.8	4366.5	15794.3	4814.1	2.0	3.5	906.5	276.3	
	43	180	100	4466.5	15693.5	4783.4	1.0	1.7	903.0	275.2	
	44	166	98.1	4564.6	15593.5	4752.9	4.0	6.9	901.2	274.7	
13	45	150	92.2	4656.8	15495.4	4723.0	2.0	3.2	894.4	272.6	272.6
	46	150	99.4	4756.2	15403.2	4694.9		0.0	891.1	271.6	
	47	152	99.8	4856.0	15303.8	4664.6	0.00	0.0	891.1	271.6	
	48	152	101.2	4957.2	15204.0	4634.2	2.00	3.5	891.1	271.6	
	49	160	102.4	5059.6	15102.8	4603.3	2.00	3.6	887.6	270.5	
	50	182	98.4	5158.0	15000.4	4572.1	3.00	5.2	884.0	269.5	
14	51	214	102.8	5260.8	14902.0	4542.1	6.00	10.8	878.9	267.9	267.9
	52	244	38.3	5299.1	14799.2	4510.8	1.00	-0.7	868.1	264.6	
	53	244	18	5317.1	14760.9	4499.1	49.00	18.0	868.7	264.8	
	54	239	117.6	5434.7	14742.9	4493.6	0.00	0.0	850.7	259.3	
	55	239	32.9	5467.6	14625.3	4457.8	2.50	1.4	850.7	259.3	
	56	239	258.9	5726.5	14592.4	4447.8	0.00	0.0	849.3	258.9	
	57	239	39.4	5765.9	14333.5	4368.9	7.00	4.8	849.3	258.9	
	58	236	185.1	5951.0	14294.1	4356.8	0.00	0.0	844.5	257.4	
	59	236	116.8	6067.8	14109.0	4300.4	0.25	0.5	844.5	257.4	
15	60	158	148.3	6216.1	13992.2	4264.8	1.00	2.6	844.0	257.2	257.2
	61	162	268	6484.1	13843.9	4219.6	0.50	3.4	841.4	256.4	
	62	162	148	6632.1	13575.9	4137.9	0.25	0.6	837.9	255.4	
	63	162	150.3	6782.4	13427.9	4092.8	1.00	2.6	837.3	255.2	
	64	187	149.7	6932.1	13277.6	4047.0	1.25	3.3	834.7	254.4	
16	65	204	143.8	7075.9	13127.9	4001.4	0.50	1.3	831.4	253.4	253.4
	66	238	133.2	7209.1	12984.1	3957.6	0.10	0.2	830.1	253.0	
	67	238	138.1	7347.2	12850.9	3917.0	0.25	0.6	829.9	253.0	
	68	238	143.4	7490.6	12712.8	3874.9	0.10	0.3	829.3	252.8	
	69	238	147.2	7637.8	12569.4	3831.2	0.50	1.3	829.1	252.7	
	70	238	150.3	7788.1	12422.2	3786.3	1.00	2.6	827.8	252.3	
	71	238	146.7	7934.8	12271.9	3740.5	0.10	0.3	825.2	251.5	
	72	208	64.4	7999.2	12125.2	3695.8	0.25	0.3	824.9	251.4	
17	73	174	123.5	8122.7	12060.8	3676.1	1.00	2.2	824.6	251.3	251.3
	74	174	124.9	8247.6	11937.3	3638.5	1.25	2.7	822.5	250.7	
	75	166	106	8353.6	11812.4	3600.4	0.50	0.9	819.7	249.9	

Thursday-8

Figure 25.2. Example detailed field collection notes, page 2.



Stream Geometry Woek Temp. Model:

Change Node	Reach	Azimuth (Compass) (Deg.)	Weighted Azimuth	Average Weighted Azimuth	Azimuth Model (Deg.)	Average Azimuth per Node (Radians)	Cline:		Cline:		Cline:	
							Right (Deg.)	Left (Deg.)	Right (Rad.)	Left (Rad.)	Right *wt (Rad.)	Right by node (Rad.)
1	1	224	27.59526	220.921	40.92	0.714200	32	40	0.56	0.70	0.07	0.748640
	2	229	37.99113				32	50	0.56	0.87	0.09	
	3	226	46.58837				41	38	0.72	0.66	0.15	
	4	227	36.91360				52	32	0.91	0.56	0.15	
	5	215	36.37483				57	25	0.99	0.44	0.17	
	6	205	35.45745				41	28	0.72	0.49	0.12	
2	7	188	46.44871	193.609	13.61	0.237521	42	34	0.73	0.59	0.18	0.758828
	8	183	66.31295				45	40	0.79	0.70	0.28	
	9	207	80.84726				43	40	0.75	0.70	0.29	
3	10	221	67.55687	205.382	25.38	0.443008	29	39	0.51	0.68	0.15	0.719233
	11	195	45.88507				34	36	0.59	0.63	0.14	
	12	195	46.34715				54	36	0.94	0.63	0.22	
	13	206	45.59336				52	36	0.91	0.63	0.20	
4	14	146	146	146.000	-34.00	-0.593412	44	48	0.77	0.84	0.77	0.767945
5	15	191	90.96999	187.858	7.86	0.137143	44	54	0.77	0.94	0.37	0.777085
	16	185	96.88770				45	63	0.79	1.10	0.41	
6	17	165	34.74354	157.810	-22.19	-0.387291	28	47	0.49	0.82	0.10	0.657282
	18	169	32.58773				40	47	0.70	0.82	0.13	
	19	150	29.15541				36	48	0.63	0.84	0.12	
	20	154	30.05167				46	35	0.80	0.61	0.16	
	21	151	31.27150				39	36	0.68	0.63	0.14	
7	22	103	37.23422	113.349	-66.65	-1.163279	54	52	0.94	0.91	0.34	1.006679
	23	110	36.19607				68	41	1.19	0.72	0.39	
	24	129	39.91871				51	65	0.89	1.13	0.28	
8	25	157	31.61827	166.133	-13.87	-0.242024	46	34	0.80	0.59	0.16	0.871989
	26	160	32.57199				41	34	0.72	0.59	0.15	
	27	169	32.82661				85	43	1.48	0.75	0.29	
	28	169	34.37060				41	39	0.72	0.68	0.15	
	29	176	34.74558				38	74	0.66	1.29	0.13	
9	30	187	65.81967	194.167	14.17	0.247258	37	49	0.65	0.86	0.23	0.763799
	31	204	66.75409				41	70	0.72	1.22	0.23	
	32	192	61.59305				54	45	0.94	0.79	0.30	
10	33	176	43.97801	174.795	-5.20	-0.090838	46	47	0.80	0.82	0.20	0.908339
	34	169	41.84882				53	46	0.93	0.80	0.23	
	35	170	42.39380				44	47	0.77	0.82	0.19	
	36	184	46.57471				65	50	1.13	0.87	0.29	
11	37	225	81.87762	219.182	39.18	0.683857	45	46	0.79	0.80	0.29	0.757339
	38	224	69.94123				44	50	0.77	0.87	0.24	
	39	208	67.36325				41	50	0.72	0.87	0.23	
12	40	164	32.94423	174.847	-5.15	-0.089942	49	50	0.86	0.87	0.17	0.889242
	41	180	36.30221				45	51	0.79	0.89	0.16	
	42	184	37.07215				49	41	0.86	0.72	0.17	
	43	180	35.97841				52	58	0.91	1.01	0.18	
	44	166	32.54967				60	44	1.05	0.77	0.21	
13	45	150	23.30637	157.709	-22.29	-0.389043	65	40	1.13	0.70	0.18	1.004303
	46	150	25.12639				75	45	1.31	0.79	0.22	
	47	152	25.56386				56	41	0.98	0.72	0.16	
	48	152	25.92248				56	42	0.98	0.73	0.17	
	49	160	27.61038				48	47	0.84	0.82	0.14	
	50	182	30.17997				46	46	0.80	0.80	0.13	
14	51	214	24.18025	235.489	55.49	0.968468	51	57	0.89	0.99	0.10	0.946201
	52	244	10.27170				50	60	0.87	1.05	0.04	
	53	244	4.827434				60	45	1.05	0.79	0.02	
	54	239	30.89294				70	40	1.22	0.70	0.16	
	55	239	8.642668				53	43	0.93	0.75	0.03	
	56	239	68.01176				53	43	0.93	0.75	0.26	
	57	239	10.35018				53	43	0.93	0.75	0.04	
	58	236	48.01450				53	67	0.93	1.17	0.19	
	59	236	30.29764				47	43	0.82	0.75	0.11	
15	60	158	27.11026	165.644	-14.36	-0.250564	42	39	0.73	0.68	0.13	0.669146
	61	162	50.23255				38	41	0.66	0.72	0.21	
	62	162	27.74036				38	41	0.66	0.72	0.11	
	63	162	28.17146				37	50	0.65	0.87	0.11	
	64	187	32.38910				42	52	0.65	0.87	0.11	
16	65	204	27.49058	231.608	51.61	0.900725	41.5	51.5	0.73	0.91	0.10	0.668681
	66	238	29.70818				37	42.5	0.72	0.90	0.09	
	67	238	30.80104				37	42.5	0.65	0.74	0.08	
	68	238	31.98313				37	42.5	0.65	0.74	0.09	
	69	238	32.83066				37	39	0.65	0.74	0.09	
	70	238	33.52206				38	37	0.65	0.68	0.09	
	71	238	32.71914				36	39	0.66	0.65	0.09	
	72	208	12.55290				38	32	0.63	0.68	0.04	
17	73	174	34.63733	164.306	-15.69	-0.273908	29	35	0.66	0.56	0.13	0.555886
	74	174	35.02998				29	35	0.51	0.61	0.10	
	75	166	28.36234				32	37	0.51	0.61	0.09	
	76	128	25.70728				31	39	0.56	0.65	0.11	

Manning's n-values can be important for maximum temperature calculations. IP#13 talks about dye studies and the like, but don't ignore what information may be gleaned from PHABSIM or other habitat or substrate mapping data available. It is becoming more common to have a geomorphologist involved for sediment transport of channel morphology studies. They may be able to help interpret data about D_{50} or D_{87} substrate quantification.

If you have been keeping your eyes open, you know that stream width is very important. Almost all heat flux is taking place at this boundary. Having several estimates of stream width at different flow conditions is really almost mandatory, whether they come from hydraulic modeling studies or simply repeated empirical observations. It is not difficult to calculate SNTEMP's width exponent. Consider Figure 25.3 resulting from the spreadsheet shown in Figure 25.2:

It is not difficult to locate data on ground temperature from USGS well logs. Though the rule of thumb is that the ground, and therefore springs and lateral flow, temperature is the same as mean annual air temperature, this should be used only in a scoping mode. It does vary, however, in most cases and you can do better.

Finally, I have been taken to task for not adequately stressing quality control and quality assurance. Part of the reason I tend to be lax was mentioned above -- the models are only models and I expect that measuring to the millimeter is simply not generally worth it. However, if a job is worth doing, it is worth doing right. Be careful, take careful notes in a properly kept field notebook. Document your assumptions.

In addition, take every opportunity to hone your skills of observation. Make small predictions about the way the world works, and then learn from your successes and misses.

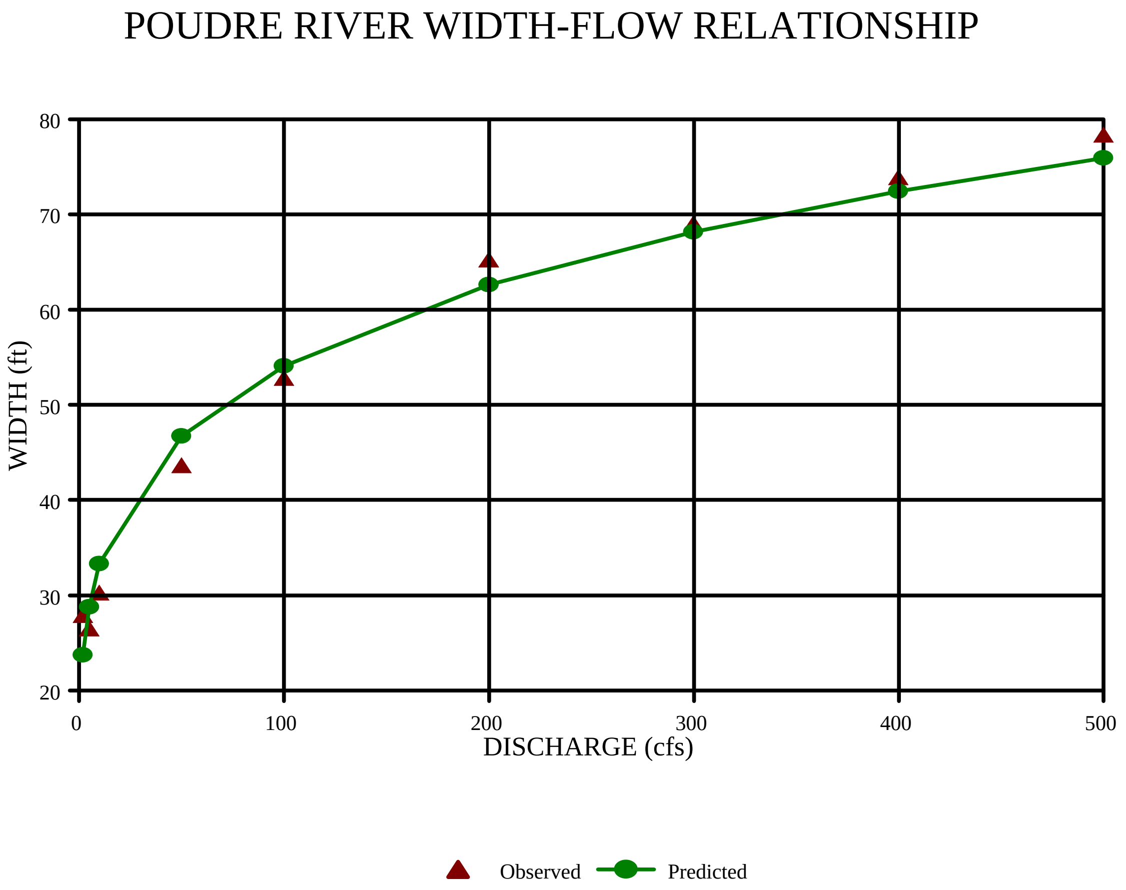


Figure 25.3. Example width versus flow relation for Poudre River.

```
A        B           C        D       E        F        G        H        I        J
1        SPREADSHEET WIDTH VERSUS FLOW RELATIONSHIP
2        POUDRE RIVER FROM PAT NELSON'S PHABSIM DATA
3
4        Martinez Park
5                                Y        X                                       Predicted
6        Q (cfs) Width (ft) @LN(Width) @LN(Q)                                        Width
7        =====================================                                    =========
8             2       27.96       3.33   0.69          Regression Output:         23.75821
9             5       26.54       3.28   1.61 Constant                   3.022065 28.81073
10           10       30.29       3.41   2.30 Std Err of Y Est           0.085492 33.33509
11           50       43.68       3.78   3.91 R Squared                  0.966518 46.77238
12          100       52.83       3.97   4.61 No. of Observations               9 54.11738
13          200       65.33       4.18   5.30 Degrees of Freedom                7 62.61582
14          300       69.10       4.24   5.70                                     68.19302
15          400       73.92       4.30   5.99 X Coefficient(s)  0.210435          72.44884
16          500       78.39       4.36   6.21 Std Err of Coef.  0.014803          75.93198
17                                                                                =========
18                                                     @AVG(Predicted Width) =    51.77594
19                                                     [to be used in shade file]
20
21                                            A-term = @EXP(Constant) =  20.53366 (feet)
22                                            B-term = X Coefficient  =  0.210435 (dimensionless)
23                                            Thus, Predicted Width = 20.53 * Q ^ 0.21
```

Figure 25.2. Example spreadsheet showing width versus flow regression relationship.

RULES OF THUMB

> "To write it, it took three months; to conceive it— three minutes; to collect the data in it— all my life." - F. Scott Fitzgerald

Ground temperature and lateral flow temperatures are equal to the mean annual air temperature.

When placing thermographs below tributaries, put them at least 100 stream widths below the confluence to avoid problems with incomplete mixing. See Information Paper 13 for more.

ADDITIONAL REFERENCES FOR TOPIC 25

Latimer, J. R. 1972. Radiation measurement. International Field Year for the Great Lakes Technical Manual Series No. 2. Atmospheric Environment Service, Environment Canada. The Secretariat, Canadian National Committee for the International Hydrological Decade, No. 8 Building, Carling Avenue, Ottawa, Canada. 53 pp.

Long, B. A. 1992. Water resources instrumentation. USDI National Park Service. Technical Report NPS/NRWRD/NRTRB92/09. Fort Collins, CO. 23 pp.

Stevens, H. H., Jr., J. F. Ficke, and G. F. Smoot. 1975. Water temperature, influential factors, field measurement and data presentation. Techniques of water-resources investigations of the USGS. Book 1, collection of water data by direct measurement, chapter D1. 65 pp.

REVIEW QUESTIONS FOR TOPIC 25

No specific questions.

TOPIC #26: LESSER-USED SNTEMP UTILITIES

Time:	0.5 hours
Format:	Lecture/Reading
Assignment:	Review notebook material
Objectives:	(1) Understand capabilities of READRYAN and TSTATS (2) Understand distinction between time major and space major data display. (3) Understand how spreadsheets can be useful in data file assembly and modification.

There are utilities on your class diskette that we will not be using in class exercises due to lack of time. You are welcome to experiment with them at your leisure to see if they might one day suit your needs. The documentation for each program is included here, but as usual, check your directory for any updates.

READRYAN

READRYAN, developed by USGS, may be useful in creating a nice summary of data collected by Ryan TempMentors. It handles delayed deployment and arbitrary sampling intervals.

TSTATS

This utility is a convenient way to summarize gaging station data for water temperature. TSTATS calculates a variety of summary statistics and produces a nice table for inclusion in reports. It has some quirks, but may work for you. See the example along with the documentation.

Data Preparation

I also wanted to mention that the data files required by SNTEMP can be effectively managed by spreadsheets. There are some examples of spreadsheets, e.g., GEOMETRY.WK1, on you class diskettes. These can (1) simplify the task of data entry in terms of keeping to the proper columns, (2) be used to convert from one set of units to another, and (3) be useful in performing kinds of sensitivity analysis not currently handled by global calibration in SNTEMP. For example, the width or width exponents may be easily multiplied by a constant in a spreadsheet whereas in an editor it would be a repetitive manual process.

Temperature Model Technical Note #10

The READRYAN Program, Version 1.0

The READRYAN program is a small, simple program useful in reading and organizing the ASCII output files from the Ryan Tempmentor program RTM. It provides synthesis of daily values from hourly averaging periods and writes a matrix suitable for import to Lotus 1-2-3 or other compatible spreadsheet.

Without repeating all the steps from the RTM documentation, use the “F2 Recover” function to download your data from the TempMentor. This will create a binary file with a “TM” prefix, for example: TM900717.005, indicating instrument 900717, deployment 005. Then use the “F5 Report” function to create ASCII files. This will result in two additional files with the prefixes “TA” and “TH”, which are respectively the ASCII data and Header data. For example, the TH900717.005 looks like:

```
Ryan TempMentor 1.0
5 minutes / sample
max. = 42.4 degrees C.
min. = 10.0 degrees C.
06/14/88  20:53:00  SN900717  #005
```

and a portion of the TA900717.005 looks like:

```
 21.5
 22.3
 18.1
 18.1
 18.4
 18.4
 18.6
 18.6
 18.6
 18.7
 18.8
 18.6
 18.2
 18.0
 17.8
 17.6
 17.4
 17.6
```

The header file will remind you when the TempMentor was activated, but this may not be the same time that it was placed in the water. It will also remind you of the sampling interval, e.g., 5 minutes. I frequently do not connect the probe until emersion. This makes it easy to see when the recorder started, because the TempMentor will store a -32.2 value, or something like that when the probe is not connected.

Now you are ready for the READRYAN program. It expects that you are running it in the same directory as your TH and TA data files, else you will get an error. It will look like this:

```
THIS PROGRAM READS THE HEADER (TH) AND ASCII (TA) FILES
PRODUCED BY RYAN SOFTWARE AND PRODUCES A PRN-TYPE FILE
TO IMPORT (/DIN) TO LOTUS 1-2-3.

DATA WILL BE OUTPUT AS HOURLY AVERAGES WITH DAILY SUMMARIES.
ONLY FULL DAYS WILL HAVE SUMMARY STATISTICS.

RYAN FILES IN THIS DIRECTORY ARE:

C:\RYAN\OBSERVED
TM900717.005
18059264 BYTES FREE

ENTER SIX DIGIT RYAN ID & EXTENSION AS 123456.123?
```

To this, you would answer as appropriate, in this case 900717.005. Incomplete answers will result in an error. The program will now print out the header file and prompt you for:

```
ENTER NUMBER OF OBSERVATIONS TO SKIP BEFORE 'REAL' DATA
ACCOUNT FOR CENTERING THE AVERAGING PERIOD IF YOU WISH?
```

This gets at the idea of the pre-deployment time lag mentioned earlier. Accounting for “centering” addresses the idea of what observations to use to represent an hourly temperature. For example, if you want the temperature for 13:00, you may wish to average the samples from 12:30 to 13:29. Thus, this prompt really asks how many observations to skip so that the program starts averaging on the boundary you choose. You must have your own notes about when you deployed the instrument and develop your own scheme.

Let’s look at an example. In the above listing, TempMentor was started at 20:53. It appears that it wasn’t put into the water until the third observation. At 5 minutes per sample, the actual deployment would be 21:03. In this case, it is essentially on an hour boundary, so we only need to skip 2 observations and start at hour 21 if we want to. If we wanted hourly-centered averaging, it would be appropriate to skip 8 observations, resulting in the first hour being 22.

The next prompt will be:

```
ENTER FIRST HOUR OF OBSERVATION ON DAY 1 (0 TO 23)?
```

which means what is the first full hour to be counted, e.g. hour 21 (or 22 if you skip 8 observations) in the above example. And then:

```
ENTER NUMBER OF SAMPLES PER HOUR (E.G. 10 MIN = 6)?
```

in this case, 5 minutes equals 12 samples.

The file produced by READRYAN will then be 900717.PRN suitable for import into 1-2-3 using the File Import Numbers routine (/FIN), and will look partially like a mess. Don't worry. It will look a lot better when you import it. Only full days will be summarized. If you want more, you'll have to do it by hand.

It is always a good idea to double-check the results to make sure that the program did what you wanted it to. In addition, it may be wise to rename the PRN file so that the next time you read from this TempMentor you will not overwrite the file you just created.

That’s all.

```
Ryan TempMentor 1.0
1 hours / sample
max. = 17.4 degrees C.
min. = -32.2 degrees C.
  10/01/92  09:00:00  SNSTB101  #001

STEELBRIDGE OF THE TRINITY RIVER. SET TO RECORD AT HOURLY
INTERVALS STARTING 0900 HRS ON 10/1/92. PROPERTY OF THE
USFWS IN LEWISTON 916-778-3536

DAY/HOUR     0        1     . . .        22       23   ABSMAX   ABSMIN   24-AVG
======   ======   ======    ======   ======   ======   ======   ======   ======
       1                    . . .         11.4     11.3
       2     11.1     11.1  . . .         11.6     11.1     12.3     10.8    11.51
       3     11.1     10.8  . . .         11.8     11.5     12.6     10.3    11.46
       4     11.1     10.9  . . .         11.7     11.4     12.6      9.9    11.32
       5     11.1     10.8  . . .         11.7     11.4     12.5      9.6    11.18
       6     11.1     10.8  . . .         11.6     11.3     12.5      9.7    11.15
       7     10.9     10.5  . . .         11.7     11.4     12.2      9.2    10.94
       8     11.1     10.8  . . .         11.6     11.3     12.2      9.8     11.1
       9     11.1     10.8  . . .         11.8     11.5     12.3      9.8    11.18
      10     11.3       11  . . .         11.8     11.6     12.1      9.7    11.11
      11     11.3     11.1  . . .         11.8     11.6     12.2      9.6    11.13
      12     11.3       11  . . .         11.8     11.6     12.2      9.8    11.16
      13     11.3       11  . . .         11.6     11.3       12      9.4    10.93
      14     11.2     10.8  . . .         11.3     11.1     11.7      9.4    10.81
      15     10.8     10.4  . . .         11.2     11.1     11.3      8.9    10.39
      16     10.8     10.6  . . .         11.3     11.1     11.5      9.3    10.65
      17     11.1     10.8  . . .         11.3     11.3     11.6      9.2    10.68
      18     11.1     10.8  . . .         11.4     11.3     11.7      9.7     10.9
      19     11.1     10.9  . . .         11.3     11.1     11.6      9.6    10.82
      20     11.1     10.8  . . .         10.8     10.8     11.1      9.8    10.41
      21     10.7     10.6  . . .         11.1     11.1     11.7     10.1    10.95
      22     10.9     10.8  . . .         11.1     11.1     11.6       10    10.83
      23     10.9     10.8  . . .         11.1     11.1     11.5      9.9    10.77
      24     10.8     10.8  . . .         11.3     11.1     11.3      9.3     10.6
      25       11     10.8  . . .           11     10.8     11.3      9.9    10.73
      26     10.7     10.5  . . .         11.1     11.1     11.3      9.4    10.49
      27     10.9     10.8  . . .         11.3     11.3     11.3      9.9    10.74
      28     11.2       11  . . .         10.5     10.4     11.2     10.3    10.56
      29     10.4     10.3  . . .         10.4     10.3     10.7      9.8    10.25
      30     10.3     10.3  . . .         10.3     10.3     10.6      9.5    10.19
      31     10.3     10.3  . . .         10.4     10.5     10.5      9.8    10.22
      32     10.4     10.4  . . .         11.1     11.1     11.3     10.2    10.78
      33     11.1     11.1  . . .         11.1       11     11.7     10.5     11.1
      34     10.8     10.8  . . .         10.8     10.8     11.1      9.8     10.6
      35     10.5     10.5  . . .         10.8     10.8       11      9.8    10.45
      36     10.8     10.7  . . .         10.8     10.7     11.1      9.9     10.6
      37     10.5     10.5  . . .         10.5     10.6       11      9.8    10.43
      38     10.4     10.5  . . .         10.5     10.5       11      9.7    10.42
      39     10.3     10.2  . . .          9.5      9.3     10.3      8.6     9.63
      40      9.2        9  . . .          8.8      8.7      9.2      7.5     8.53
      41      8.6      8.4  . . .          8.4      8.3      8.6      7.3     8.13
      42      8.1        8  . . .          8.7      8.6      8.8      6.7     7.92
      43      8.6      8.5  . . .          8.9      8.8      8.9      7.3     8.34
      44      8.7      8.7  . . .          9.1        9      9.2      7.8     8.63
      45      8.9      8.8  . . .          9.1        9      9.2        8     8.72
      46      8.9      8.8  . . .          8.9      8.8      9.1      7.8     8.65
      47      8.7      8.6  . . .          9.6      9.6      9.6      8.1     8.79
      48      9.6      9.6  . . .          9.8      9.8     10.4      9.3     9.84
      49      9.8      9.7  . . .          9.9      9.8     10.2      9.1     9.68
      50      9.8      9.8  . . .          9.6      9.4     10.3      9.2     9.73
```

TSTATS Version 2.0

by

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August 1995

INTRODUCTION

TSTATS is a program used to read Lotus 1-2-3 data files of daily maximum and minimum water temperature data and create summary statistics of that data. It has been used in conjunction with data downloaded from the EarthInfo CD-ROM database only, and it has not been tested with other vendors' products, e.g. Hydrodata.

USAGE

The 1-2-3 WK1 worksheets must have been downloaded and available in the working directory. They must be named with six alphanumerics and a suffix, as in 123456MX.WK1 and 123456MN.WK1. We have used the 3rd to 9th digit of the USGS gage as the 6-digit identifier for record keeping purposes.

TSTATS is driven by a series of command line options in the form:

```
tstats [-f] [-y1nnnn] [-y2nnnn] [-r[gage number]] <-axx.x> <-cxx.x> <-dxx> <gage number>
```

where:

-f	prints table footnotes
-y1nnnn	inputs the beginning year (nnnn) - defaults to first year
-y2nnnn	inputs the ending year (nnnn) - defaults to last year
-r	performs a temperature/flow regression. If an 8-digit gage number is included, it will be used as the source for the flows; otherwise, the same gage as the temperatures will be used

-axx.x	inputs acute temperature threshold - required input xx.x is the desired temperature
-cxx.x	inputs chronic temperature threshold - required input xx.x is the desired temperature
-dxx	inputs the chronic temperature duration - required input

gage number is the 8-digit temperature gage number to analyze - required input. NOTE: the first two digits are assumed to be 11. This should change in future releases.

TSTATS is a demanding program that potentially reads a large quantity of data and makes numerous calculations. It may take a while on a slower computer to complete. While running, TSTATS will print progress messages such as “Processing Oct Temperature/flow regression completed.”

TSTATS creates five output files:

1. TABLE1.TXT - Text output of summary statistics
2. TABLE1.PRN - Spreadsheet importable format of above
3. TABLE2.TXT - Text output of monthly averages
4. TABLE2.PRN - Spreadsheet importable format of above
5. TABLE3.TXT - Text output of regression statistics

Note: Footnotes, if requested, will not be written to spreadsheet format.

OUTPUT

Table 1A. Example selection of TABLE1.TXT, including footnotes.

```
KLAMATH RIVER BL IRON GATE DAM CALIF
Gage # - 11516530        (Flow Gage for Temperature Regression - 11516530)
Years: 1963 - 1980
Acute Threshold: 20.0C  Chronic Threshold:K15.0C  Duration:   7

                                                            Threshold
        Average Temperatures (Celsius)           Extremes   Exceedence
     -----------------------------------   Day  ----------  ----------
Mon    N   Mean   Med   Max   x+SD   Min   Var   Max   Min  Acut  Chrn   A2
(1)   (2)   (3)   (4)   (5)   (6)    (7)   (8)   (9)  (10)  (11)  (12)  (13)
---  ----  ----  ----  ----  -----  ----  ----  ----  ----  ----  ---- ------

Oct   552  13.9  13.9  14.1  15.92  13.7   0.4  19.4   9.0  0.00  0.11  -1.53
Nov   484   9.2   9.5   9.4  11.26   9.1   0.3  13.5   4.5  0.00  0.00  -1.04
Dec   503   4.8   5.0   4.9   6.37   4.6   0.3   9.4   0.5  0.00  0.00  -0.16
Jan   548   3.0   3.0   3.1   4.24   2.8   0.3   6.2   0.5  0.00  0.00   0.20
Feb   509   4.0   4.0   4.2   5.35   3.8   0.3   7.0   1.0  0.00  0.00   0.32
Mar   551   6.6   6.5   6.8   8.50   6.3   0.5  12.0   3.0  0.00  0.00   0.63
```

For the data accompanying each station, the following column footnotes are applicable:

1. Twelve monthly periods. Days in the period are adjusted for leap year.

2. N is the number of days in the period having both a maximum and minimum water temperature. May be missing days or years.

3. Mean is the mean daily water temperature over the N observations.

4. Med is the median daily water temperature over the N observations.

5. Max is the average maximum daily temperature in the period. Note that there may be more than N observations for the maximum daily temperatures.

6. x+SD is the average maximum daily water temperature plus the standard deviation of the maximum daily water temperature.

7. Min is the average minimum daily temperature in the period. Note that there may be more than N observations for the minimum daily temperatures.

8. DayVar is the average daily variation (max-min) in temperature for the period.

9. Extreme Max is the maximum daily temperature in the period. Note that there may be more than N observations for the maximum daily temperature.

10. Extreme Min is the minimum daily temperature in the period. Note that there may be more than N observations for the minimum daily temperature.

11. Threshold Exceedence Acut is the number of days in the period exceeding the stated mean daily acute temperature threshold divided by N. In effect, this value is the probability of acute occurrences of the threshold temperature for all days in period of record for each month and is read on the right-most graph axis.

12. Threshold Exceedence Chrn is a tally of the number of events of X sequential days in the period (run length) exceeding the specified chronic threshold, divided by N. As an example, if the number of days defining a run is seven, and there were 10 days in a row exceeding the mean daily temperature threshold, there would be four 7-day runs tallied. In effect, this value is the probability of chronic occurrences of the threshold temperature for the full sequence of days in the period of record for each month and is read on the right-most graph axis.

13. A2 is the A2 constant in the following regression equation relating water temperature to flow:

$$T = A_1 + A_2*LN(Q) + A_3*SIN(B) + A_4*COS(B)$$

where:
T = Average Mean Daily Temperature
$A_1..A_4$ = Regression Coefficients
Q = Discharge
B = Julian Day * 2PI / 365.25

The output from TSTATS has been used as input to many other analyses. In addition, the spreadsheet data has been imported into a Quattro “template,” TSTATTMP.WQ1, also included on the distribution disk. Loading data into this format will produce a graph like that shown below:

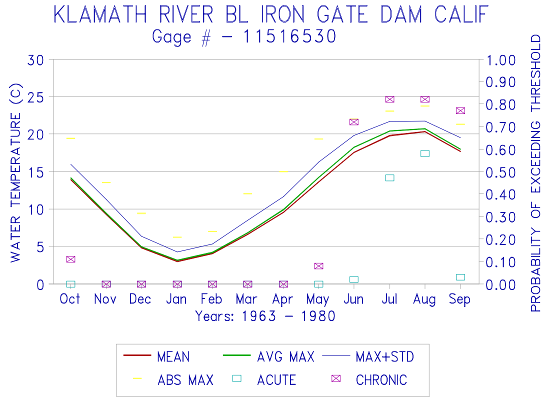

Figure 26.1. Example plot from data produced by TSTATS utility.

Table 1B. Example portion of the spreadsheet form of Table 1.

```
"KLAMATH RIVER BL IRON GATE DAM CALIF"
"Gage # - 11516530      "
"Years: 1963 - 1980"
"Acute Threshold: 20.0C  Chronic Threshold: 15.0C  Days in Run:   7"

"Mon" "N" "AMean" "AMed" "AMax" "x+SD" "AMin" "DayVar" "Max" "Min" "Acute" "Chronic" "A2"


"Oct"   552  13.9  13.9  14.1  15.92  13.7   0.4  19.4   9.0  0.00  0.11  -1.53
"Nov"   484   9.2   9.5   9.4  11.26   9.1   0.3  13.5   4.5  0.00  0.00  -1.04
"Dec"   503   4.8   5.0   4.9  6.37   4.6   0.3   9.4   0.5  0.00  0.00  -0.16
"Jan"   548   3.0   3.0   3.1  4.24   2.8   0.3   6.2   0.5  0.00  0.00   0.20
"Feb"   509   4.0   4.0   4.2  5.35   3.8   0.3   7.0   1.0  0.00  0.00   0.32
```

Table 2. Selection of TABLE2.TXT output.

```
KLAMATH RIVER BL IRON GATE DAM CALIF
Gage ID     : 11516530

     Water  Mean
Mon  Year   Temp
---  -----  ----
Oct  1963   13.3
Nov  1963    9.0
Dec  1963    5.4
Jan  1963    2.7
Feb  1963    4.7

NOTE:  MISSING DATA SHOWS UP AS 0.0 IN TABLE 2.
```

Table 3. Example of the Table 3 output. The columns represent the coefficients of the regression equation, A1 through A4.

```
Oct  18.43  -1.53  -8.88  -6.45
Nov   5.10  -1.04 -14.94   2.35
Dec  18.67  -0.16  -2.04 -13.75
Jan  15.25   0.20  -3.44 -13.62
Feb  13.85   0.32  -5.68 -12.05
Mar   7.09   0.63  -3.66  -7.55
Apr  21.96  -0.80  -7.44  -4.17
May  13.60  -0.92  -0.92 -10.99
Jun  17.06  -1.07  -0.83  -8.33
Jul  23.42  -2.18  -7.28  -9.38
Aug  10.40  -0.39  -6.36 -11.64
Sep  19.24  -0.64  -1.27  -7.32
```

OTHER REQUIREMENTS

As mentioned, to create the graphs as shown, the Quattro template TSTATTMP.WQ1 may be used. If running the temperature/flow regression, the file TFIT.EXE must be present in the local directory and two temporary files get created: TEMPS.IN and REGCO.OUT. Note that we have been leery of the regression because of the influence of intervening flows.

TOPIC #27: OTHER SNTEMP UTILITIES

Time:	2.5 hours
Format:	Hands-On Small Group Exercises/Discussion
Assignment:	SNTEMP Exercises 27.1 and 27.2 (with break as needed).
Objectives:	Understand and apply TDELTAQ and TTMPFIT.

Other utilities we will discuss include TDELTAQ and TMPFIT. The first you will likely use for sure. The second is a maybe. Exercises and documentation are included here for you to get the idea.

TDELTAQ

This utility allows you to change the flows in a network, typically at an **S** or **D** node, and have those changes cascade downstream. You can imagine why this is an important feature, especially in the network model.

TMPFIT

We have found this program useful in a variety of settings. It created a statistical model of temperatures using the formula:

$$T_j = A_0 + A_1 * LN(Q_j) + A_2 * COS(b_j) + A_3 * SIN(b_j)$$

for the *j*th time period. The trigonometric functions (sin and cos) substitute for most of the meteorology and the discharge (Q) is also factored in. Though you must remember the limitations of statistical models, they can help tremendously if you need quick answers to what-if questions. See documentation attached. You may need it for your exercise.

Exercise 27.1 - TDELTAQ

Practice applying TDELTAQ to your Upper Colorado River data set to solve the problem that you worked on “by hand” in exercise 22.3.

Exercise 27.2 - TMPFIT

Using the uncalibrated Upper Colorado River data set, use TMPFIT to determine what the discharge should be at Ouray to meet your established temperature threshold for what seems to be the most difficult month to meet. How does the answer you get relate to what you learned from applying TDELTAQ manually?

RULES OF THUMB

"There are three kinds of lies: lies, damned lies and statistics." - Benjamin Disraeli

Rather than a trial-and-error procedure to establish the temperature versus discharge relationship, TMPFIT will provide a good first approximation. It also may be advantageous to use relations developed with TMPFIT in a negotiation setting where one may want relatively fast feedback and running SNTEMP quickly may not be possible.

SUGGESTED READINGS FOR TOPIC 27

None in addition to the documentation.

REVIEW QUESTIONS FOR TOPIC 27

Under what circumstances would the temperature versus discharge relation developed with TMPFIT NOT be appropriate?

ANSWERS FOR TOPIC 27

As has been discussed, regression formulations will not work well if anything about the system changes dramatically. A wholly new set of reservoir operations may well change the temperature of the discharge, for example. A new discharge temperature, then, may invalidate a TMPFIT relation developed from pre-reoperation data.

Temperature Model Technical Note #9
Program DELTAQ - Version 3.1
12/07/1994

INTRODUCTION

The program DELTAQ modifies the flow for a selected node in an SNTEMP hydrology data file and cascades the change downstream. The change in flow may be entered as:

1 - an absolute replacement value

2 - a constant by which all values are multiplied

3 - a change in flow (delta Q)

4 - a list of absolute replacement values in an external file

Changes for multiple years and time periods for the node may be made in a single pass. Changes for multiple nodes can also be made; however, the program handles only one node on each "pass".

The most reasonable flow changes would be to Structure (**S**) and Diversion (**D**) nodes, i.e. gaming with flow changes to determine temperature consequences. Headwater (**H**) flow changes are allowed, as well. Flows below discontinuous (non-flow through) Structures will remain unchanged; however, the inflow value for the structure will be modified to reflect inflow changes above the structure. No reservoir water budget balancing will be performed.

The DELTAQ program can currently handle up to ten years and 366 time periods of data.

Note: DELTAQ assumes that the input hydrology data file is correct. As all nodes downstream from the selected node are changed, DELTAQ should not be used to correct errors in the hydrology data file.

PROGRAM EXECUTION

The DELTAQ program is executed through the TDELTAQ batch file. To execute the program, enter the following line:

tdeltaq <job control file> [output file] [report file]

where the job control file is required, and the output and report files are optional. The hydrology data file and hydrology node file are also required with file names supplied by the job control file. If the report file is included, the program will create a report listing all hydrology nodes, year and time period of any changes, original discharge, and the new discharge. Note that the output file name must be entered if the report is desired.

DELTAQ will begin by displaying a numbered list of nodes. If there are more nodes than can fit on the screen, the list will pause with the following prompt displayed at the bottom of the screen:

(MORE) PRESS <ENTER> TO CONTINUE.

This prompt is displayed after each screen except the last. When all nodes have been listed, the program prompts for the node selection.

ENTER THE NUMBER OF THE NODE TO BE CHANGED:

After a node has been selected, the program displays a numbered list of all available years with the following prompt:

ENTER THE NUMBER(S) FOR THE YEAR(S) TO BE CHANGED:

Any number of years may be selected. Enter the numbers of the years separated by commas. Ranges of years may be entered by separating the first and last years by double periods (..). For example, assume the following line has been entered:

1..3,5

This line selects years 1, 2, 3, and 5.

DELTAQ then displays a numbered list of available time periods followed by the selection prompt. Time periods are selected using the same format as the years. Individual time periods, ranges, or any combination of these may be selected.

Note: The program will make flow changes for the selected node, for all selected time periods, within all selected years.

After the years and time periods are selected, the program prompts for the method of flow change.

```
ENTER METHOD OF CHANGE:

1.  ABSOLUTE REPLACEMENT VALUE
2.  MULTIPLICATION BY CONSTANT
3.  CHANGE IN FLOW (DELTA Q)
4.  ABSOLUTE REPLACEMENT VALUES FROM EXTERNAL FILE
    :
```

Enter the number for the method of change. If options 1, 3 or 4 are chosen, the system prompts for the units of change. Units may be either Cubic Meters per Second (CMS) or Cubic Feet per Second (CFS.)

When this is complete, the program prompts for the actual change values (or file name if changes are in an external file).

```
ENTER THE NAME OF THE FILE CONTAINING THE CHANGES:
```

or

```
ENTER CONSTANT FOR MULTIPLICATION
ENTER UP TO   14 VALUES.
    ?
```

When using an external file, the file must contain a number of change values equal to the number of years selected times the number of time periods selected. For example, if 17 years are selected, each with 52 time periods, the external file must contain 884 values in a single column. Values are read from the file in order of time periods within years. Therefore, the third value would be from time period three in year one, assuming three or more time periods per year. The program will prompt for a new file name for each node changed.

For each time period selected, in each year selected, an appropriate value must be entered. Therefore, if two years and seven time periods are selected, 14 values must be entered. Values are entered for all time periods within a year before the next year is entered. Values may be entered as individual values separated by commas, by repetitions, or any combination. Repetitions are entered by using an asterisk (*) to separate the repetition number from the value. For example, 3*1.2 enters the value 1.2 three times. All values need not be entered on the same input line. When a line is full, press <ENTER>. The program will prompt for additional values, updating the number of expected values. When the correct number of values has been entered, the program will continue with program execution. If more values have been entered than are required, DELTAQ responds with the following error message:

ERROR: MORE VALUES HAVE BEEN ENTERED THAN ARE REQUIRED! PLEASE REENTER.

In the following example, two years and seven time periods have been selected. The changes are being made by multiplication factor (option 2), and the user has entered the 14 values as follows:

*1.25,5*1.3,1.1,3*1,3*1.2,1.5*

Note that the user has entered 1 as a value for three of the year/time period combinations. This technique allows seven time periods to change in the first year and four in the second while making only a single pass. This technique can be easily used when changes are by factor or delta Q; however, when absolute flow values are entered, the user must supply the original value in order for no changes to take place.

The values entered are displayed in the following table.

Time Period	Year 1	Year 2
1	1.25	1.0
2	1.3	1.0
3	1.3	1.0
4	1.3	1.2
5	1.3	1.2
6	1.3	1.2
7	1.1	1.5

If the number of values entered does not match the number of expected values, the following error message is displayed.

ERROR: NUMBER OF VALUES ENTERED DOES NOT MATCH THE NUMBER OF CHANGES REQUESTED.
Requested changes:
Values entered:

The system then prompts for complete reentry of the values.

A maximum of 999 repetitions can be made for a single value and a maximum of 3660 values (10 years x 366 time periods) can be entered.

When all values have been entered, the system will process the data for the information entered. Note that for **S** nodes, if the structure is a flow through node, any existing upstream inflow values, while not required, will be modified for the change in flow. If the structure is not flow through, no changes will be made downstream from the structure.

When the hydrology data file has been completely processed, the following prompt is displayed.

DO YOU WISH TO MAKE ADDITIONAL CHANGES ? 1.) YES 2.) NO ?

If 1 is selected, the nodes are redisplayed and the user is prompted to select a new node to change.

If 2 is selected, the program completes execution. The prompt

BUILDING REPORT . . .

is displayed if a report filename was entered on the program execution command line. When the report is completed, the program displays the message

REPORT WRITTEN TO FILE filename.

An example report follows.

```
Original file: KVRFHYD.DAT                                  1/11/1994
New file     : test.out                                     7:41:54

All discharge values are in CMS.
                                         TIME    ORIGINAL       NEW
              NODE                YEAR  PERIOD   DISCHARGE   DISCHARGE
--------------------------------  ----  ------   ---------   ---------
GREEN RIVER     S 1S2      661.3   NO CHANGES
GREEN RIVER     B          556.7   NO CHANGES
YAMPA RIVER     H 1        681.5    2      6       20.600      23.432
YAMPA RIVER     H 1        681.5    2      7       70.320      73.860
YAMPA RIVER     S   5      652.0    2      6       21.167      23.999
YAMPA RIVER     S   5      652.0    2      7       69.609      73.149
YAMPA RIVER     B          638.8    2      6       21.421      24.253
YAMPA RIVER     B          638.8    2      7       69.291      72.831
LITTLE SNAKE    H 1        651.6   NO CHANGES
LITTLE SNAKE    T          638.8   NO CHANGES
YAMPA RIVER     J          638.8    2      6       29.807      32.639
YAMPA RIVER     J          638.8    2      7       92.583      96.123
YAMPA RIVER     T          556.7    2      6       31.386      34.218
YAMPA RIVER     T          556.7    2      7       90.605      94.145
GREEN RIVER     J          556.7    2      6       76.548      79.380
GREEN RIVER     J          556.7    2      7      154.346     157.886
GREEN RIVER     V 1S       485.9    2      6       77.910      80.742
GREEN RIVER     V 1S       485.9    2      7      152.640     156.180
GREEN RIVER     E          399.0    2      6       80.489      83.321
GREEN RIVER     E          399.0    2      7      152.640     156.180
```

ERROR/WARNING MESSAGES

This section lists additional error and warning messages not discussed in the text above.

```
ERROR:  INVALID TIME PERIOD: n
        CHECK FOR CORRECT NUMBER OF TIME PERIODS
        IN JOB CONTROL FILE
```

A time period in the time period file was found to be blank. This error could be caused by using input files that do not have the same number of time periods.

```
ERROR:  NO ZZFILES FOUND, DID YOU USE TDELTAQ?
```

The DELTAQ program is intended to be run from the TDELTAQ.BAT file.

```
ERROR OPENING JOB CONTROL FILE
ERROR OPENING HYDROLOGY NODE FILE
ERROR OPENING HYDROLOGY DATA FILE
```

Check the full path and file name for the appropriate file.

```
ERROR: NUMBER OF TIME PERIODS EXCEEDS MAXIMUM OF 366!
ERROR: NUMBER OF YEARS EXCEEDS MAXIMUM OF 10!
```

DELTAQ can handle a maximum of 10 years and 366 time periods. If these values are exceeded contact the maintenance programmer.

```
ERROR IN READING JCF FILE
ERROR IN READING HYDROLOGY NODE FILE
ERROR IN READING HYDROLOGY DATA FILE
```

DELTAQ assumes the required files are error free. If any of these errors occur, check the appropriate file for potential errors.

```
ERROR READING INPUT!
```

An error occurred reading your input selections or values. Check typing and reenter the input.

```
YOUR SELECTION IS NOT VALID.
DO YOU WISH TO SEE THE LIST AGAIN (Y/N) ?
```

A selection was made that is not in the selection list.

WARNING: ILLOGICAL NODE CHANGE. NODE TYPE - X
where: X = **B**, **T**, **J**, **E**, **V**, **K**, or **S** (flow through only.)

It is not logical to change the flow at these nodes under normal circumstances; however, changes are allowed.

WARNING: DISCHARGE LESS THAN OR EQUAL TO ZERO!
NODE: node description

The change requested has caused the flow at node n to be less than or equal to 0. Only the original flow at node n will be subtracted from the appropriate nodes downstream.

WARNING: INFLOW VALUES EXIST WHERE NOT REQUIRED!
VALUES BEING ADJUSTED BASED ON FLOW CHANGES.
NODE: node description

The hydrology data file has upstream inflow values at an **S** node, but the node is flow through and the values are not required. The values will be adjusted based on the flow change.

WARNING: INFLOW VALUE MISSING FOR INTERNAL S NODE!
NODE: node description

The hydrology data file has a non-flow through **S** node that is missing upstream inflow values.

WARNING: S NODE INFLOW LESS THAN OR EQUAL TO ZERO!
NODE: node description

The change in flow has reduced the upstream inflow below zero.

TMPFIT PROGRAM

by Alan Moos
June 6, 1994

Revised by Jeff Sandelin
June 7, 1994

INTRODUCTION

The TMPFIT program is an auxiliary program for the Stream Network Temperature Model. It uses predicted maximum and average temperatures and discharges from SNTEMP to develop parameters for maximum and average temperature at each node of the stream based on the equation:

$$T_j = A_0 + A_1 * LN(Q_j) + A2 * COS(b_j) + A_3 * SIN(b_j)$$[1]

where:

where:	T_j	= Average Mean Daily Temperature
	$A_0..A_3$	= Regression Coefficients
	Q_j	= Discharge for Time Period
	b_j	= First Day of Time Period in Radians:
	b_j	= Julian Day * 2Pi/365.25

EXECUTION

The TMPFIT program must be run using the batch file TTMPFIT.BAT. If TTMPFIT is entered with no file names, information about input and output files will be displayed as follows:

```
        syntax  TTMPFIT KVRTMP ZOUT

    where  KVRTMP = Average and Maximum temperature results from SNTEMP
               (input)
           ZOUT = Regression Results and Statistics (output)
```

---

[1] This equation was adapted from: Bartholow, J. M. 1989. Stream Temperature Investigations: Field and Analytic Methods; Instream Flow Information Paper No. 13. U.S. Fish and Wildlife Service. Biological Report 89(17). p. 87

Note: KVRTMP may also be a free format file containing the Julian
dates, flows, and temperatures for a single node.

The fixed format KVRTMP (TABLE XI) is created by SNTEMP with the option 14 set to ‘T’ or ‘"’. The free format file may contain any number of comment lines designated by a semicolon in the first column, and data lines consisting of three values per line (Julian date, flow, and temperature). If the INVALID INPUT FILE error is received, check that the proper file type has been selected.

ALGORITHM

The TMPFIT program uses a least squares algorithm[2] with singular value matrix decomposition to estimate the regression parameters. The least squares algorithm was chosen because it is the closest to a non-linear fit, and does not require derivatives of the component functions (the LN(Q_j) component function does not have a derivative with respect to time.) The singular value decomposition method eliminates the possibility of problems if the equations are very close to singular[3]. The least squares algorithm also allows a lot of flexibility in the form of the temperature equation. The subroutine FUNCS calculates the components of the equation for each time period. This subroutine could be adapted in the future to include different terms for air temperature, shade, etc.

In addition to the flexibility of the equation used for TMPFIT, another factor may also be useful. The SIG variable is an array of individual standard deviations, which can be used to “weight” individual temperature values. It is currently set to 1, since measurement errors have not been estimated[4]. This causes all points to be considered equally in the development of the regression parameters. Decreasing the SIG values will put more emphasis on the extreme temperature values. This may be useful in developing an equation that includes extreme temperatures, although the overall error will increase. Increasing the SIG values will put more of an emphasis on the mean temperatures. The temperature equation can be smoothed by using higher SIG values. Individual points can be made “more important” by decreasing the SIG for specific points.

---

[2] Adapted from: Press, William H., Brian P. Flannery, Saul A. Teukolsky, and William T. Vetterling. 1986. Numerical Recipes: The Art of Scientific Computing. Cambridge University Press, New York. 818 pp.

[3] See Press, p. 515.

[4] See Press, p.510.

OUTPUT

The output from TMPFIT includes given and estimated values for average and maximum temperature (or for the single temperature in the case of a free format file), the regression parameters, average absolute error and Chi Squared. Output can also be produced with titles in quotes for spreadsheet applications.

The average absolute error is expressed both in degrees of temperature and in percent. This is the easiest error statistic to understand, as it is the mean of the absolute errors divided by the mean of the observed temperatures. The Chi Squared value is a statistical parameter based on the error and standard deviation at each point[5].

TMPFIT also gives the option to plot given and estimated temperatures for each node and each year. This can also be useful in evaluating the quality of the regression equation. Average, Estimated Average, Maximum, and Estimated Maximum temperatures are shown on the same graph and labeled A, B, C, and D respectively. For a free format input file, A and B represent the given and estimated temperatures, respectively. The time is shown in Julian days, measured from the first day of the first year. In other words, if a data set starts on October 1 and continues through February, the Julian days will begin with 274 (Oct. 1), continue through to 365 (Dec. 31), and then proceed to 366 (Jan 1 of next year) and so on. Only complete years will be graphed based on the number of observations in the first year.

In many circumstances, the estimated temperatures may be very poor. This suggests that factors not related to time or discharge are affecting the temperatures at each node.

HISTORY

Version 1.0 - Original version.
Version 2.0 - Added graphical verification.
Version 2.6 - Modified to handle free-format input files.

---

[5] See Press, p. 502.

TOPIC #28: MUDDY STREAMS

Time:	0.25 hours
Format:	Student feedback
Assignment:	Each student writes 1 to 3 questions about issues still puzzling them.
Objectives:	For instructor to understand and be prepared to clarify continued confusion.

In a classroom setting, and just prior to breaking up for the day (or proceeding on a field trip), each student is asked to write down 1 to 3 questions that still seem unclear or have not been adequately addressed. They are encouraged to state their questions or concerns as clearly as possible. The instructor(s) take the questions, organize them into useful categories, and think about how to approach them during Topic 30.

In a self-study format, e-mail questions to your instructor.

RULES OF THUMB

If one person has a question, others do too.

TOPIC #29: METEOROLOGICAL DATA: THE PROMISE AND THE REALITY

Time:	Optional -- 1 hour
Format:	Field Trip; Q&A
Assignment:	Review notebook material
Objectives:	(1) Understand kinds of data collected by established met stations. (2) Understand biases inherent in meteorological data.

When the class is taught in Fort Collins, we usually arrange to meet with Colorado's State Climatologist, Nolan Doeskin, for a tour of the Fort Collins meteorological station located on the Colorado State University campus. The tour is interesting and informative. Nolan usually explains each piece of equipment, its biases, and to some degree, its evolution through time. He is also a wealth of information on the kinds of errors made by typical weather observers. Students typically learn something about who to talk to get meteorological data and the kinds of questions to ask. Nolan is quite a character, to boot.

Alternately, visit one or more web sites routinely providing data. Some that I know about are the Colorado Climate Center (http://ccc.atmos.colostate.edu), the Western Regional Climate Center (http://www.wrcc.dri.edu) and the National Climatic Data Center (http://www.ncdc.noaa.gov). The WRCC is a part of the Desert Research Institute at the University of Nevada at Reno and can supply a large amount of valuable data.

RULES OF THUMB

> " 'Tain't what a man don't know that hurts him, its what he knows that just ain't so."

– Frank McKinney Hubbard

Did you know that the Celsius scale was originally reversed, i.e., 100 was freezing and 0 was boiling? Thank goodness somebody turned that around!

TOPIC #30: QUESTIONS FROM DAY 4

Time:	1 hour
Format:	Discussion
Assignment:	None specific; already accomplished in Topic 28.
Objectives:	Clarity, perspective, and understanding.

After the fourth full day, covering Topics 25-29, students are generally feeling comfortable with the model, have specific things that they are eager to try when they get the chance, and are of course understandably getting restless to return home. If they participated in the field trip to the meteorological station yesterday, they may either feel somewhat elated that they are "off the hook" as they have learned that the meteorological data isn't always as accurate as they might have thought. Alternately, they may be discouraged for the same reason. This session is meant to (1) group the questions submitted in Topic 28 into logical groups; (2) answer those questions to the degree possible; and (3) leave room for additional questions as they emerge.

In a classroom setting, the instructor(s) have grouped the questions into logical categories. This facilitates going through them in an orderly manner and helps to show what element or elements may need more review or discussion.

If taking the self-study class and you haven't done so already, take a moment and e-mail any questions to the instructor.

TOPIC #31: MODEL REVIEW FOR THE MODELER AND THE REVIEWER

Time:	1 hour
Format:	Class Discussion
Assignment:	Review notebook material
Objectives:	(1) List items students feel are important in model application review. (2) Synthesize items into coherent categories. (3) Understand importance of documenting data sources and assumptions.

This topic is perhaps more directed to the model reviewer than the model developer, user, or data collector. It assumes that you work for a regulatory agency of some sort and you have been given the responsibility to review someone else's work for technical competence. Remember, the study has already been completed, at least to some level; you do not have the opportunity at this point to have input to the study objectives unless the work was so shoddy that it's "back to the drawing board".

If you are in a classroom setting, students will come to the front board and write items they think are important in model review on yellow stickies, pasting each to the wall, for a period of 10-15 minutes. Then two students are chosen to organize the stickies into logical categories. (**NOTE**: Need several stacks of 3x5" yellow stickies and several wide tip markers for this exercise.)

If you are a self-study participant, take 10-15 minutes to jot down items you think are important in your own categories.

ANSWERS FOR TOPIC 31

What follows are not true answers, as no definitive answer can be provided. They are the result of previous classes' work on this problem organized as a checklist of questions.

CHECKLIST FOR REVIEWING A RIVER TEMPERATURE STUDY

I. <u>ARE THE OBJECTIVES CLEAR?</u>

- Biological criteria appropriate to management objectives?
  - All life stages of concern covered?
  - Problems acute or chronic?
  - Relevant and measurable variables?
    - Expressed appropriately?
      - Daily mean or maximum?
      - Daily variation (max-min)?
      - Degree days?
      - Miles of suitable stream?
      - Thermal refuge inundation?
      - Magnitude, frequency, duration, timing, and rate of change all addressed?
- Study area appropriate?
  - Spatial extent covers both biology and management?
  - Spatial resolution ok?
- Temporal extent appropriate?
  - Covers all times of interest?
  - Resolution (time step) appropriate to problem?
  - Baseline period representative?
- General realm of management alternatives stated?
  - Flow, channel, riparian vegetation, timing?

II. <u>IS THE MODEL SELECTION APPROPRIATE?</u>

- Tried and true in similar circumstances?
- Institutionally-recognized validity?
- Assumptions met?
  - Steady or dynamic flow?
  - Time step appropriate for travel time?
  - Dimensionality appropriate?
  - Ice problems?
- Linkage to reservoir model ok?

III. IS INPUT DATA QUALITY OK?

- Flow sources and sinks detailed enough for management study?
- Met data representative of study area?
- Geometry data detailed enough for management study?
- Temperature data ok?
  - Continuous or grab sample?
  - Installed out of mixing zones?
  - Calibrated to ASTM source?
- Missing data handled appropriately?
  - Smoothed or filled?
  - Error analysis provided?
- Has all of this been documented?

IV. IS THE CALIBRATION PROCESS OK?

- Does it meet the “rational man” test?
- Calibration global, or local in space or time?
- Significant deviation from default parameters?
- Goodness of fit criteria presented?
  - Mean error, rmse, maximum error, probable error, r^2?
- Error analysis through both time and space provided?
  - Any systematic error?

V. HAS THE MODEL BEEN EXERCISED TO PROVIDE MANAGEMENT GUIDANCE?

- Alternative scenarios analyzed?
  - Origin of synthetic input data?
  - Representative and meaningful extremes tested?
- Extrapolation violates model assumptions or strains parameters?
- Altered thermal regimes modulate species phenology?

VI. WAS THE COMMUNICATION DONE WELL?

- Appropriate results clearly communicated to all affected and responsible parties?
- Has the application been peer reviewed?
- Has there been enough public participation or explanation?

Rules of Thumb

Model results may be useful even if wrong if its error is comparable with the accuracy of management decisions or if simply knowing the direction of change is important. Just be careful.

TOPIC #32: SPECIAL TOPICS (DEPENDING ON CLASS INTEREST)

Time: 1 hour (depending on time available)
Format: Lecture/Reading
Assignment: Review notebook material
Objectives: (1) Know about other water temperature models for special applications.
(2) Know about the use of SNTEMP in integrated biological modeling.
(3) Understand degree-day and MWAT calculations.
(4) Understand possibilities for model “cheating” and its prevention.

This “final” topic should be tailored to the needs of individual students and their questions. None of the material that follows is mandatory, as discussion can lead in a variety of directions, limited only by the time available. These are simply examples of the kinds of questions that have previously arisen.

Other Water Temperature Models

There are a variety of stream temperature models for different purposes. They are all physically based, rather than strictly empirical, and consequently, they all do a good job on what they do. The deciding factors between them depend more on your objectives, your budget, and your time frame than anything else. I’ll just mention a few, taking material largely from promotional literature.

Temp86 - TEMP-86 is a computer model that simulates stream temperature responses that result from the removal of streamside vegetation. This model is based on a temperature simulation model previously developed by Beschta and Weatherred (1984). Management of forest cover in streamside zones alters the amount and distribution of energy available to a stream. These changes can affect stream temperatures and influence the quality of fish habitat. Since fish populations are directly and indirectly affected by temperatures, potential temperature increases resulting from the loss of shade should be considered during the design and scheduling of forest harvesting operations along streams. The TEMP-86 MODEL can simulate temperature responses for a wide range of alternative streamside prescriptions on either and/or both sides of a stream. These prescriptions can include (1) complete harvest of all vegetation, (2) buffer strips of varying width and canopy density, and (3) partial cuttings or thinnings. The model was designed with small (<10 cfs) streams in mind.

TEMP-86 requires three general types of information: site characteristics, stream characteristics and characteristics of the stream-adjacent vegetation. Once these characteristics have been specified for a given stream section, alternative harvest strategies (clearcut, buffer strips, etc.) can be evaluated for identifying potential impacts to stream temperatures. To examine the temperature effects from harvesting streamside vegetation, the model is first run based on the existing streamside conditions (the CONTROL). Then, an anticipated streamside harvest practice (the TREATMENT) is simulated to predict changes in stream temperature.

TEMP-86 is able to simulate energy transfer processes involving solar and longwave radiation through forest canopies, and conductive heat transfer between bedrock and the stream. It also allows for groundwater inputs along the stream section of interest. The model does not include heat transfer by convective or evaporative processes; these heat transfer processes are generally considered to have a minor effect on stream temperatures. The model assumes 'clear-sky' conditions for all simulations (i.e., simulations cannot be run for cloudy days).

The TEMP-86 MODEL simulates stream temperatures using an accounting procedure (energy budget) that assesses energy transfers (inputs and outputs) for a specific stream reach or stream section. Any imbalance between energy inputs and outputs cause a change in heat storage (i.e., a change in water temperature) for the stream section. Ideally, characteristics of the stream and streamside vegetation should not change significantly along the reach. For example, the stream section should not change in aspect, and shading from topography or vegetation should be relatively uniform throughout the section. Groundwater seepage (when specified) is assumed to occur uniformly along the stream section.

I am not sure of the availability of TEMP-86, either software or training.

BLTM. The Branched Lagrangian Transport Model is a US Geological Survey product that uses Lagrangian calculations that are unconditionally stable and based upon a reference frame that moves at a velocity equal to the mean channel flow velocity. BLTM results are within the accuracy required by most water-quality studies. The BLTM is easily applied to unsteady flows in networks of one-dimensional channels with fixed geometry and tributary inflows. Reaction kinetics for up to 10 constituents are provided in a user-written decay-coefficient subroutine. Postprocessor plot programs improve the utility of the model. The model routes any number of interacting constituents through a system of one-dimensional channels.

The model solves the one-dimensional convective-diffusion equation with reaction kinetics. Data requirements include flows (with areas, top widths, and velocities at each grid point needed for each time step), initial conditions (concentration of each constituent at each grid at time zero), boundary conditions (concentration of each constituent at upstream junctions and in each tributary during each time step). Data are output in text files. Postprocessor programs are available to produce graphical and tabular summaries.

The program is used primarily on UNIX-based computers with support for Data General AViiON and Sun SPARC stations. A version is also available for DOS-based computers having a math coprocessor. Written in Fortran, BLTM should be easily installed on other platforms, however, postprocessing programs use Computer Associates' DISSPLA software. Official versions of U.S. Geological Survey water-resources analysis software are available for electronic retrieval via the World Wide Web (WWW) at: *http://h2o.usgs.gov/software/*, and via anonymous File Transfer Protocol (FTP) from: *h2o.usgs.gov (path: /pub/software)*.

Documentation includes: Jobson, H.E., and Schoellhamer, D.H., 1987, Users manual for a Branched Lagrangian transport model: U.S. Geological Survey Water-Resources Investigations Report 87-4163, 73 p.

Training, Modeling Flow and Transport in a Riverine Environment (G0203), is offered annually at the USGS National Training Center. Contact U.S. Geological Survey, Office of Surface Water, Harvey Jobson, 415 National Center, Reston, VA 20192, hejobson@usgs.gov.

QUAL-2e. QUAL-2E is the standard for small, one-dimensional streams to medium sized rivers. Though it could be used for "large" streams, its desirability would shift in favor of WASP. QUAL-2E simulates 15 water quality constituents using mass balance approach. These include DO, temperature, nitrogen (organic, ammonia, nitrite, nitrate), phosphorous (organic and dissolved), algae as Chlorophyll a, arbitrary non-conservative, CBOD (ULT or 5-day), conservative minerals (3), coliform bacteria. QUAL-2E models dendritic stream systems with tributaries and junctions. It accepts multiple loads - point discharges, non-point loads/losses, unsimulated tributaries, water withdrawals. It simulates steady state or diurnal water quality responses (but not fluctuating flows). QUAL-2E is sponsored by the Environmental Protection Agency (EPA) with technical assistance available and some training classes occasionally offered. QUAL-2E supports contemporary (1975-1982) modeling theory, but only handles quasi-steady-state hydraulics. However, dynamic water quality may be explored by providing diurnal meteorological data. QUAL-2E is well documented. Being a one-dimensional, steady state (or slowly varying flow) model, the advective and dispersive components are relatively easy to calibrate and "validate" and has been done several times. Developed cooperatively by the National Council for Air and Stream Improvement (NCASI), the Department of Civil Engineering at Tufts University and EPA, it is academically recognized as incorporating the state-of-the-art diurnal kinetics, especially for algal-nutrient interactions and the complete nitrogen series. Unfortunately, if you do not want to use their version of the kinetics, you may be out of luck. This model offers an option to compute the amount of flow augmentation necessary to reach a specified water quality goal, specifically dissolved oxygen. It supports a general network layout, with some constraints on the number of nodes. Stream geometry is generalized, but adequate. It supports both English and metric data entry and output. QUAL-2E supports all the common water quality variables and can generate output as tables or (line printer) graphs. I am not sure about linkages with other models, but some data entry "helper" programs are available. An interesting "risk analysis" package for modeling under uncertainty is also available as the model QUAL-2EU. As previously mentioned, training classes are offered occasionally, either by the EPA or the NCASI. In addition, there seems to be a shift to more WASP than QUAL training. Notification of courses has also been a problem in the past.

HEC-5Q. HEC-5Q is an optimization model, one of a very few that has been used to simulate both rivers and reservoirs. This model was developed by the U.S. Army Corps of Engineers (COE) at the Hydrologic Engineering Center (HEC) at Davis, California (USACOE, 1986). HEC-5Q simulates the sequential operation of a reservoir system to evaluate the operational "rules" for flood control and conservation (i.e., instream flow) purposes. It is meant to handle not only water quality, but also water supply, hydropower, and flood control -- multi-purpose, multi-constraint kinds of issues. Its strengths are in balanced reservoir system regulation and optimization of water supply. It is used not only for planning, but also in real-time applications.

HEC-5Q is actually a simplistic water quality model piggybacking on a sophisticated water management program (HEC-5). It only handles temperature, DO, and three conservative and three non-conservative constituents. Reservoir releases may be computed to satisfy multiple control point (node) criteria using a philosophy of minimizing "violations" of control point water quality requirements. HEC-5Q has some capability to simulate multilevel reservoir withdrawal to accomplish downstream water quality objectives. Twenty reservoirs, forty control points, and any length of study period up to one year can be simulated on an hourly, daily, or monthly time interval. Its primary disadvantage is its complexity, typically requiring months to apply. Input requirements may include the use of HEC-2 for the stream geometry and a separate program to calculate the equilibrium water temperatures from meteorology. The model has a long history of supported use and is in the public domain. HEC-5Q is fairly well documented (all things considered) and available from the COE-HEC group. Technical assistance used to be generous, but may be more difficult now that knowledgeable people have retired. Briefings may be offered at COE facilities on demand, but no formal training is regularly given.

WQRRS. The Water Quality for River-Reservoir Systems model is another HEC-developed program. Written in FORTRAN, this model is available for DOS-based computers. The flow and water quality can simulate conditions around branching islands. The reservoir component handles 1-dimensional vertical stratification. The stream component includes the capability to handle unsteady flow routing. The model is complex and relatively difficult to use. It has not been widely applied outside of Corps projects.

Heat Source. This program is quite similar to SSTEMP in that it is intended for use in a single stream reach. It differs from SSTEMP, however, in that it is a dynamic model, one that simulates at an hourly time step. This technique appears to be especially good if you are interested in maximum (or minimum) daily temperature, and more particularly the duration of that exposure. Note that this implies that one must supply hourly meteorology to calculate hourly output. The algorithms have been captured in both an executable program as well as Excel spreadsheet format and are attractively presented with excellent graphical displays. I am not sure what the latest incarnation is. Contact Dick Pederson, Oregon DEQ, Portland, 503-229-6345 for more information or Matt Boyd's home page at http://www.spiretech.com/~mattboyd/index.html.

MWAT Calculations

The Maximum Weekly Average Temperature (MWAT), sometimes used in conjunction with criteria developed by EPA, is just that: it is the maximum of a continuous, 7-day running average of mean daily water temperatures. What's that you say? Assume that you had a continuous record of mean daily temperatures. For any specified period of time (a week, a month, a season, or a year) the MWAT should be calculated in a manner similar to that proposed by Ferraro, et al. (1978). They discussed several methods of calculating the MWAT and concluded that the most accurate method was to use a method that most closely reflected the temperatures actually experienced by the aquatic system. This method computes a 7-day running average for the average water temperature for each day in the period of record, that is, 1 to 7 January, 2 to 8 January, etc. In this fashion, a continual "flow" of mean daily temperatures is computed. Then the maximum value for each day across all years is chosen. In our case, the maximum value for all January 7ths would be chosen for the period 1970 to 1978, followed by the maximum of all January 8ths, and so forth.

As an example of calculating the Maximum Weekly Average Temperature (MWAT), I have chosen a small (18.2 sq. mi.) drainage in south-central Idaho called Little Boulder Creek, a tributary of the Salmon River. Records were obtained for a gage on this stream 11 miles south of Clayton, ID, that recorded daily discharge, as well as daily maximum and minimum water temperature from 1970 to 1978. Daily air temperature records for the same period were obtained from nearby Challis, ID. These records were summarized as follows:

In working with "real world" data one inevitably encounters problems. Data gaps were frequent in this data set, so one simplifying measure was taken. There had to have been at least 5 days (with both a maximum and minimum water temperature observation) in the week prior to a given day in order to calculate that day's MWAT. If there were only five days, the average was taken for those five days only. If this method resulted in no calculation of a MWAT for a particular day, the maximum across all years simply ignored that particular year.

A graph of the derived MWAT may be seen in Figure 32.1, accompanied, for perspective, by the maximum of the maximum daily water temperatures and the minimum of the minimum daily water temperatures. The maximum MWAT calculated (observed) was 13.7 C, which occurred for the week preceding 15 July.

Discharge (cfs) and air temperature (F) were summarized simply as the mean daily values for all January 7ths, January 8ths, etc. For these variables, missing data points were ignored. It is interesting to note that the maximum MWAT occurs at the time that average daily flows just begin to decline from the high runoff period as shown in Figure 32.2.

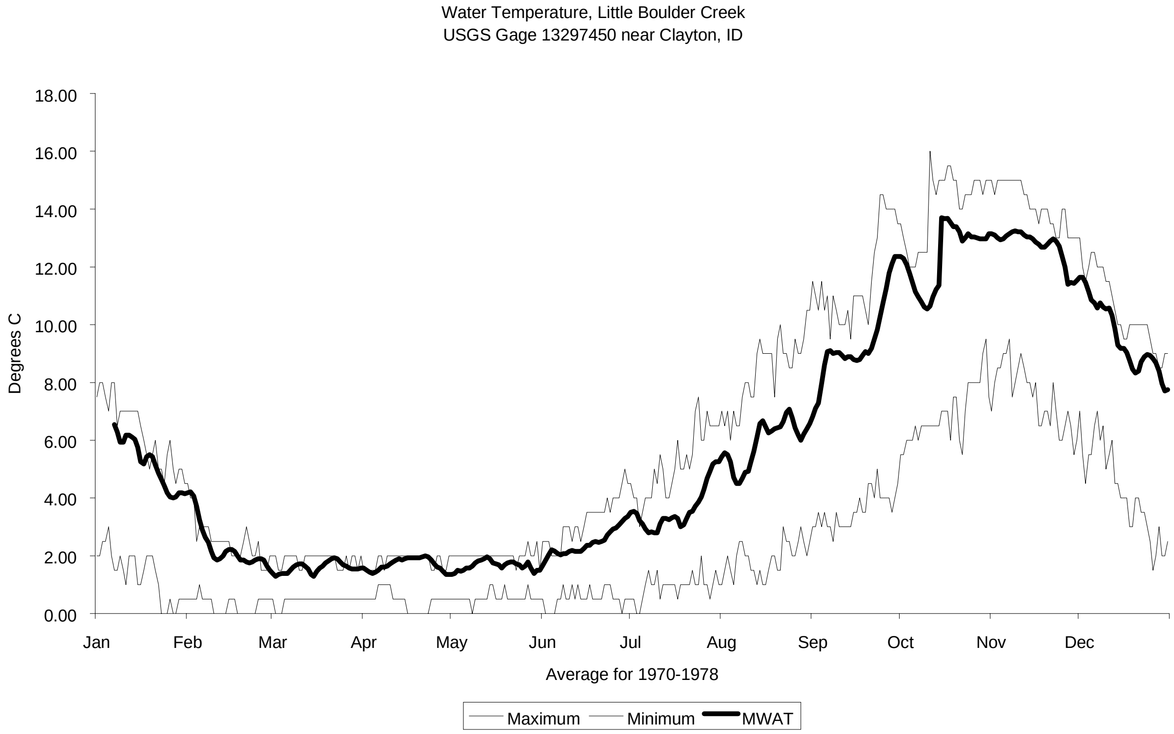

Figure 32.1. Example MWAT figure.

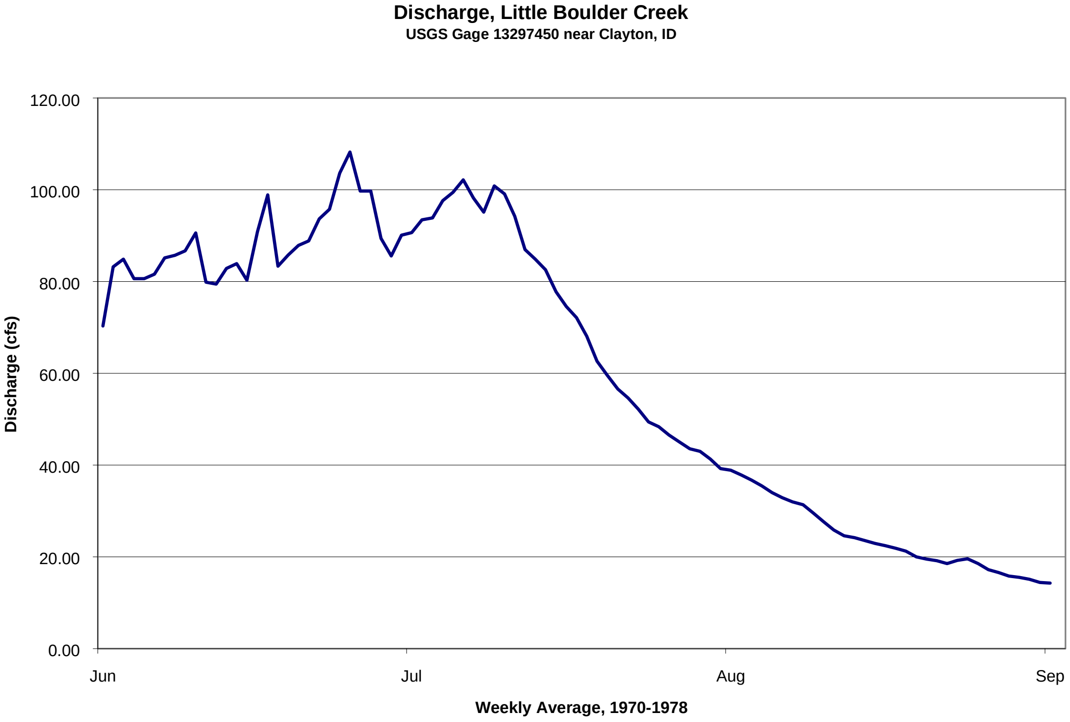

Figure 32.2. Weekly average discharge from Little Boulder Creek.

Determining The Effects of Altered Flow

Without developing a detailed process-oriented model, determining the effects of an altered flow regime on MWAT must rely on the use of an empirical regression model. It should be stressed that the use of such a model is only applicable at a single geographic point (the gage in this case) and has no value if any non-random system changes occur. Values derived should not be represented as true predictions, but rather as indications of degree and magnitude of change.

Several alternative models were constructed for the Little Boulder Creek data set described earlier. The variables tested included, minimum and maximum daily air temperature, maximum weekly average air temperature, mean daily discharge, and a variable calculated to represent all other meteorological variables in the form of a sine wave with a yearly period in a fashion similar to that employed by Theurer et al. (1984) and Bartholow (1989). The formulation finally determined to be the best for the period from June through August, representative of the highest MWATs, was:

$$\mathrm{MWAT} = a_0 * (a_1 * T_{am}) + [a_2 * \ln(Q)] + (a_3 * [T_0 + \in T * \cos((2\Pi/366) * (D_j - D_0))])$$

where MWAT = maximum weekly average water temperature (°C)

a_0 to a_3 = empirically derived coefficients

T_{am} = average daily maximum air temperature

ln(Q) = natural log of the average daily discharge (cfs)

T_0 = average historic MWAT for June through August (°C)

= 11.498°C

$\in T$ = half of the range of historic MWAT for June through August (°C) = 3.44°C

D_j = Julian day; January 1 = 1 and December 31 = 366

D_0 = phase shift (in days) = 210 days

The relationship developed was:

$$\mathrm{MWAT} = -57.578 + (0.136 * T_{am}) - [3.051 * \ln(Q)] + (5.039 * [11.498 + 3.440 * \cos(2\,\Pi/366) * (D_j - 210)])$$

with the corresponding quality criteria:

$R^2 = 0.92$

Standard error of MWAT estimate = 0.54°C

N = 93

The resulting fit between the observed MWATs and the predicted MWAT is shown in Figure 32.3.

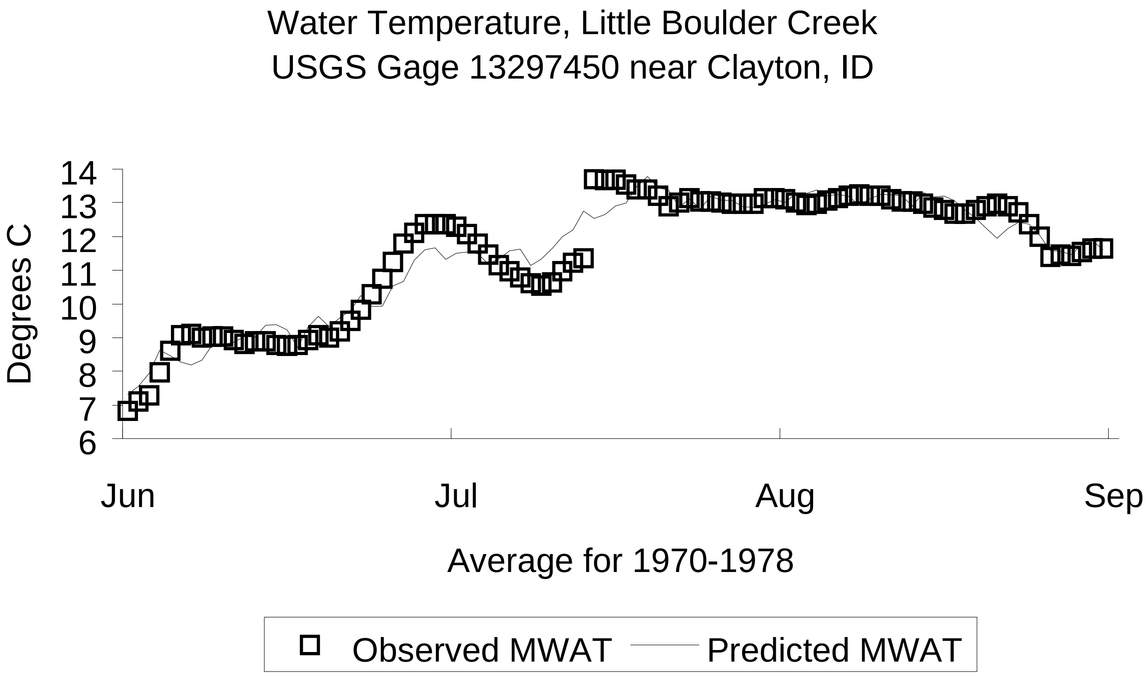

Figure 32.3. Comparison of MWATs.

So, for example, on 20 July, the day of highest predicted MWAT, the Julian day is 202, the discharge was 59.57 cfs, and the average maximum air temperature was 64.22 F. This works out as follows. Please note that this equation is sensitive to the number of significant digits retained.

$$\text{MWAT} = -57.578 + (0.136 * 64.222) - [3.051 \ln(59.5567)] + (5.039 * [11.498 + 3.4440 * \cos((2\Pi/366) * (202-210))]) = 13.78°\text{C}$$

Restating the equation to focus on the discharge term we have:

$$\text{MWAT} = 26.262 - [3.051 * \ln(Q)]$$

Thus a reduction in discharge during this period from 60 cfs to 30 cfs would imply an increase in the MWAT from 13.78°C to 22.86°C. The relationship between discharge and maximum MWAT is shown in Figure 32.4.

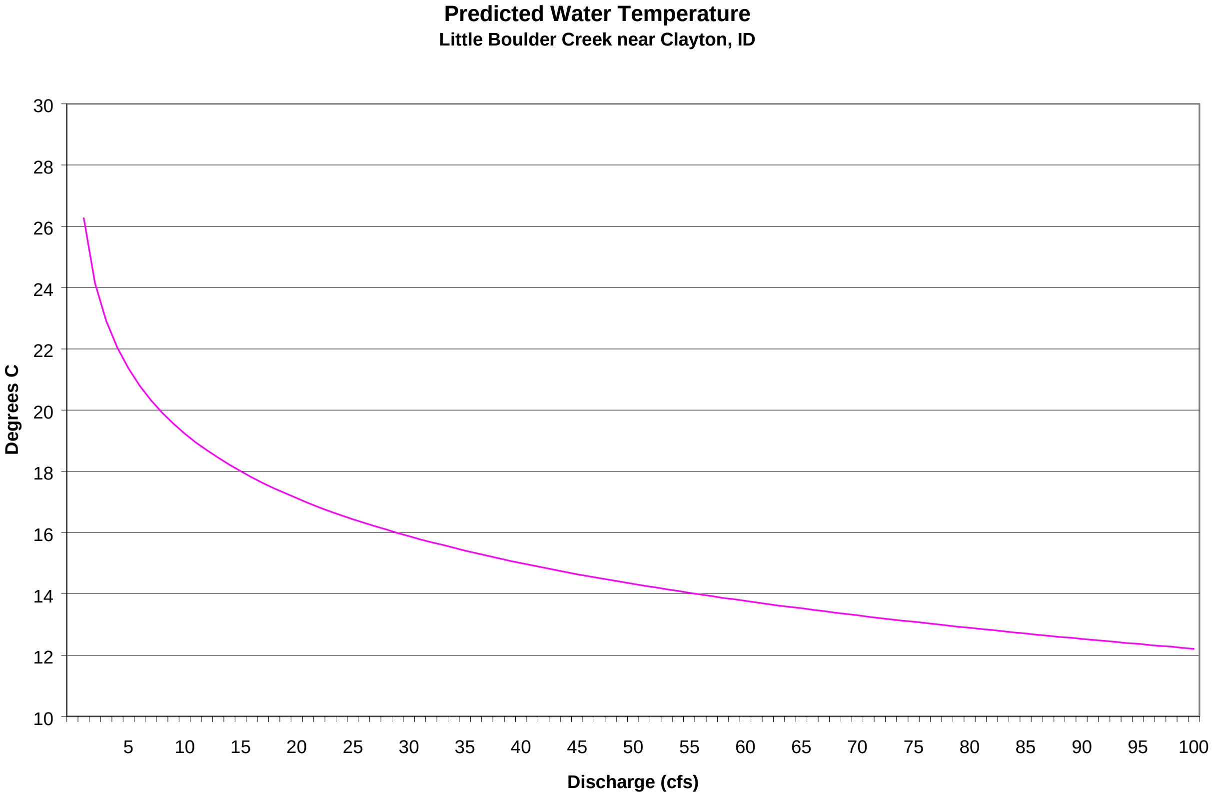

Figure 32.4. Temperature versus discharge relationship for Little Boulder Creek.

Discussion

Use of the MWAT is a reasonable one for this kind of screening-level analysis. However, we have much to learn about biological response to field fluctuating water temperatures. For example, Hokanson et al. (1977) found that rainbow trout do not respond to mean temperatures, but rather to some value between the mean and the maximum. In particular, they found that diel fluctuations around a mean reduced the yield of trout with respect to those held at that same constant mean temperature, if those means were in the upper end of the tolerance zone.

Degree-Day Calculations

I won’t say too much about degree day calculations except that we should look for research opportunities to explore the importance of growing periods and their relation to over-winter mortality, physiological maturation (for gonad or egg development), and perhaps other areas. One study with which I was somewhat involved dealt with Colorado Squawfish. Much of the water development in the Upper Colorado River basin was post-1950. For a specific location on the river, the degree-day comparison was as shown in Table 32.1. One must be careful in calculating degree-days to clearly specify the threshold, or benchmark, that triggers counting. Two different benchmarks were used for the squawfish, 20°C as the trigger for spawning activity, and 12°C, that temperature below which there is little biological activity for the squawfish. As it turns out, for the Upper Colorado River area, the hypothesis for the squawfish decline was that other non-native fish were able to compete better in the altered thermal environment, rather than a specific negative impact due to degree days.

It is well known that degree day calculations are simply an approximation of the relationships between thermal exposure and various biological responses, principally because the simple summation formulae assume a linear relationship when the “true” relation is curvilinear (Arnold, 1960). Other methods (see Crisp, 1981) are more accurate, but also more difficult to apply. We (Bartholow et al., 1993) have applied them with good success in egg incubation calculations.

Table 32.1. Days comparison degree day comparison for Walter Walker site, Colorado River for Colorado squawfish maturation, spawning, and growth degree. BM = degree day benchmark, i.e., the threshold after which counting begins.

DATABASE	MATURATION			SPAWNING			GROWTH		
	DRY (80%)	AVERAGE (50%)	WET (20%)	DRY (80%)	AVERAGE (50%)	WET (20%)	DRY (80%)	AVERAGE (50%)	WET (20%)
1930-1950	505	323	277	403	247	205	1624	1359	1163
1950-1982	651	435	285	425	256	169	1687	1425	1177
PERCENT CHANGE	+29%	+35%	+3%	5%	+3%	-17%	+4%	+5%	+1%

NOTE: SPAWNING IS UP THROUGH AUGUST, BM = 20^{o} MAX
MATURATION IS UP THROUGH JUNE, BM = 12^{o} MAX
GROWTH IS UP THROUGH OCTOBER, BM = 12^{o} MAX

Integrating SNTEMP with Biological Applications

Basically, I just wanted to mention a few different kinds of model applications. Both Cheslak and Bartholow have used SNTEMP in concert with population dynamics models, one for trout and one for anadromous salmonids. See the references.

Model Cheating

> "History is a lie agreed upon." – Voltaire

The question has arisen as to whether it is possible to detect models that have been assembled to deliberately deceive someone. I guess I've got two "answers" to this question.

First, in the best of worlds, investigations into stream temperature or any other habitat-based study should have participation from all the stakeholders in an issue. The Legal Institutional Analysis Model (Wilds, 1986; Lamb, 1987) talks about the players in the issue resolution process and their attributes. Some players are likely to be **guardians** of the way water or other resources are currently allocated, some will be **advocates** for change. Undoubtedly, these two groups look at the world differently, especially in terms of premises and assumptions. It is entirely possible that models can be constructed that paint pictures that are either not the whole truth or not nothing but the truth. In fact, I'd go so far as to say that no model can be the truth, the whole truth, and nothing but the truth. It's all a matter of degree and intention, conscious or unconscious. If there is substantive participation by all parties from definition of objectives, to data collection, to evaluation of alternatives, to display of results, the inherent biases can be minimized. Unfortunately, this ideal rarely occurs.

Second, and on a much different level, it is very unlikely that it would be possible to detect a model that was a deliberate lie. It is clear that any thermograph record, or any other electronic record for that matter, can be altered easily, as can electronic files of model results. Aside from instituting completely parallel studies, with duplication of effort from the get-go, there really is no effective way to deal with this issue. This takes us back to the previous point. If you are really leery of dealing in an adversarial setting, the best payoff will be working together from the beginning.

RULES OF THUMB

> "Nothing is so ignorant as the ignorance of certainty." – Aldous Huxley

Keep your model as simple as you possibly can and still address the study objectives in a quality fashion. Share your methods and results early and often. Be willing to put your model at risk by trying things suggested by others to show that they either are or are not sensitive or lead to different conclusions.

SUGGESTED READINGS FOR TOPIC 32

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Each of the following discusses more than one model of stream temperature.

Sullivan, K., J. Tooley, K. Doughty, J. E. Caldwell, and P. Knudsen. 1990. Evaluation of prediction models and characterization of stream temperature regimes in Washington. Timber/Fish/Wildlife Rep. No. TFW-WQ3-90-006. Washington Department of Natural Resources, Olympia, Washington. 224 pp.

Tu, S., W. Mills, and S. Liu. 1992. Temperature model evaluation and application. Habitat Evaluation Notes and Instream Flow Chronicle. Colorado State University Conference Services. January 1992. 2(1):1-3.

Tu, S. (Project Manager). 1991. Instream Temperature Model Evaluation. Pacific Gas & Electric Environment, Health, and Safety Report 009.4-90.17. June 7, 1991. Pacific Gas & Electric, San Ramon, CA. V.P.

TOPIC #33: FINAL EXAM AND COURSE EVALUATION

Time: 1 hour
Format: Exam and discussion
Assignment: Complete exam and evaluation material
Objectives: Provide both student and instructor(s) feedback on accomplishment of class objectives.

Please remove the answer sheet and course evaluation forms from your class notebook and proceed. Conclude by forwarding them to your instructor. Remember, the purpose is feedback on how well the material served its purpose, not to reflect on you.

RULES OF THUMB

> "If ignorance is bliss, there should be more happy people." – Victor Cousins

> "It's what you learn after you know it all that counts." – John Wooden

IF312 - SNTEMP CLASS

Final Exam Answer Sheet - Rip Me Out

Name: ______________________________________
Address: ______________________________________
____
____

True/False

Please circle T or F for each question.

1	T	F
2	T	F
3	T	F
4	T	F
5	T	F
6	T	F
7	T	F
8	T	F
9	T	F
10	T	F
11	T	F
12	T	F
13	T	F

Multiple Choice

1 a b c

2 a b c

3 a b c d

4 a b c d

5 a b c

6 a b c d

7 a b c d

8 a b c d

9 ____________________________

10 a b c d

11 a b c d

12 ____________ ____________ ____________ yes no

13 a b c d

14 a b c d

15 a b c d

16 a b c d

17 a b c d

18 a b c d

19 a b c

20 a b c d e

21 a b c d e

22 a b c d

23 a b c d

24 a b c

25 a b c d

26 a b c d

27 a b c

IF312 - SNTEMP CLASS

Final Exam

True/False

1. The SSTEMP and SNTEMP models can be used in either an incremental, problem solving decision environment or a standard-setting decision environment.

2. The time step used in these models must be smaller than the time it takes for water to flow from the head to the end of the network to accurately transport water (and temperature) through all nodes.

3. Much stream geometry data need not be supplied to B or T nodes because the program already knows what is upstream from these node types.

4. Flow provided at C (change) nodes is used to redefine the lateral flow between the C node and the next most upstream hydrology node.

5. The regression aids are applied to all hydrology nodes to fill in missing flow or water temperature values.

6. SNTEMP cannot be used when discharge changes gradually over a period of several days.

7. The SNTEMP and SSTEMP models, and most other stream temperature models, work better in large rivers than small streams.

8. Increasing Manning's n will always increase maximum water temperatures.

9. Electronic thermographs are always superior to mechanical thermographs.

10. The habitat mapping approach will provide better width versus flow data than a representative reach approach.

11. The preferred option for evaluating the suitability of a water temperature regime for a species is to rely on use of equations (e.g., MWAT) derived from water temperature experiments.

12. When water temperature requirement information is unavailable for a species, a temperature regime cannot be recommended for the species.

13. When water temperature regimes are evaluated, it is acceptable to apply the results without considering factors including inter-specific competition, water pollution and food availability.

Multiple Choice

Please circle or enter the correct answer for the following questions. Note that some questions may have more than one correct answer; some may have no correct answers.

1. Among the strengths of the SNTEMP model are:

    a. Lots of helper programs for data entry, formatting, etc.

    b. Sophisticated regression model for filling in missing flow values at hydrology nodes.

    c. Supplying accurate, readily available input data results in accurate, reliable mean daily water temperature predictions.

2. Among the weaknesses of the SNTEMP model are:

    a. Lack of a tie to a biological model.

    b. Empirical calculation of daily maximum water temperature.

    c. Relatively complicated data structure.

3. Applications for which SNTEMP is less well suited include:

    a. Timber harvest evaluation.

    b. Stream channel alteration.

    c. Reservoir temperature analysis, including multi-level reservoir outlet thermal release evaluation.

    d. Power plant cooling-water discharge effects on water temperature.

4. In the SNTEMP model, which kind of stream is likely to reach warmer temperatures:

   a. An east-west flowing stream with all shade (totaling 25%) from riparian vegetation.

   b. An east-west flowing stream with all shade (totaling 25%) from topography.

   c. A north-south flowing stream with all shade (totaling 25%) from vegetation.

   d. A north-south flowing stream with all shade (totaling 25%) from topography.

5. In the SSTEMP program, all other things being equal, decreasing the percent possible sun increases the mean water temperature because:

   a. Percent possible sun is influenced by the time of local sunrise/sunset. Decreasing the percent sun is equivalent to increasing the daylight time, so more solar radiation enters the water.

   b. Increasing cloud density results in a "greenhouse" effect.

   c. Treating dependent variables independently is an error.

6. Calibrating the SNTEMP model is complicated because:

   a. Missing water temperature values filled by regression models at V nodes change each time the model is run with new parameters, producing a non-linear response to changes in input values.

   b. Often there is no explicit guidance as to what one or more input parameters need to be adjusted.

   c. One is never quite sure whether the measured water temperatures are correct enough to provide valid comparisons.

   d. None of the above.

7. The validation results of SNTEMP indicate that there is a mean error of -0.10 C and a probable difference of 0.5 C. This means that:

   a. The standard deviation of the error is 0.5 C.

   b. Fifty percent of the time the model will predict within 0.5 C of the true water temperature.

c. Sixty-three percent of the time the model predictions will be between -0.6 C and -0.4 C of the true water temperature.

d. None of the above.

8. One would choose to smooth water temperatures at a specific node if:

   a. They were grab-sample observations or of suspect quality.

   b. You wanted to see the model give more accurate results.

   c. To make up for lack of good stream geometry data immediately upstream.

   d. You were working on a weekly time step model.

9. Suppose you have a simple two-branched network with the following measured values:

Branch 1 discharge = 100 cfs	Junction discharge = 125 cfs
Branch 1 temperature = 20 C	Junction temperature = 21 C

What is the water temperature of the second branch?

10. Geographic boundaries for a temperature model should be determined to one degree or another by:

    a. physical headwaters.

    b. out-of-basin water imports.

    c. where management actions may occur

    d. where all life stages of interest occur.

11. The best regression model to fill or smooth water temperature values is:

    a. The zero lateral flow heat transport regression (Option 1).

    b. The linear standard second-degree linear regression (Option 2).

    c. Whichever one gives the best R-squared value.

    d. Whichever one gives the best R-squared value provided that Option 1 has a reasonable pseudo source distance and is not below a water temperature discontinuity.

12. List three types of stream geometry nodes that do not require a definition for width, Manning's n, shade, etc.

    Do these same nodes require latitude and elevation?
    [yes or no]

13. MWAT means:

    a. the average of the maximum daily temperatures for a week.

    b. the maximum of the average weekly temperatures for a series of years.

    c. the average of the maximum weekly temperatures for a year.

    d. the maximum of the average daily temperatures for a series of weeks.

14. The SSTEMP and SNTEMP models are 24-hour average models because:

    a. all meteorology input data represents 24-hour average conditions.

    b. all solution techniques work on a 24-hour integration.

    c. all flows entering all headwater nodes must exit the system within 24 hours.

    d. all flows must be 24-hour average flows.

15. A zero-flow headwater is one for which:

    a. All flows along a segment accrue at equilibrium temperature.

    b. Should be greater than 30 km from the receiving stream, or the maximum extent of your watershed, whichever is less.

    c. Should only be on tributaries with little or no biological importance.

    d. Should be scrutinized for reasonableness and verified for accuracy, if possible.

16. Under what conditions would diverting water from a stream most likely cause a large increase in mean daily water temperature?

    a. Streamflow is very cold.

    b. Streamflow is very warm.

    c. Stream has heavy riparian vegetation.

    d. Stream has no riparian vegetation.

17. When would diverting water from a stream lower the minimum water temperature?

    a. At night.

    b. Stream has heavy riparian vegetation.

    c. Stream has no riparian vegetation.

    d. Both a and c.

18. When would diverting water form a stream lower the maximum water temperature?

    a. At night.

    b. Stream has heavy riparian vegetation.

    c. Stream has no riparian vegetation.

    d. Diversion is near a dam.

19. How is channel change modeled in SNTEMP and SSTEMP?

    a. It is not modeled in SNTEMP and SSTEMP.

    b. By changing the width A and B terms.

    c. By changing the elevation at nodes.

20. What is the difference between heat transport and heat flux?

    a. They describe parts of the same process.

    b. One describes the heat balance on a parcel of water and the other describes movement of that parcel.

    c. One tells how solar radiation, evaporation and other factors affect the water temperature and the other tells how water containing heat moves downstream.

    d. Both a and b.

    e. Both b and c.

21. SNTEMP is not a hydrology model because:

    a. It does not route water through the stream network.

    b. It does not describe groundwater movement.

    c. It does not connect diversions and return flows.

    d. It allows any discharge to be specified at any point.

    e. All of the above.

22. When simulating with monthly data the resulting water temperatures are:

    a. mean monthly temperatures.

    b. average temperatures for normal years.

    c. average mean daily temperatures.

    d. a crude approximation of the monthly temperature.

23. What node types need discharge data?

    a. Skeleton nodes.

    b. Study nodes.

    c. H, B, S, T, Q, C, K, and V nodes.

d. H, B, D, S, R, T, Q, P, K, and V nodes.

24. The Non-linear Zero Lateral Flow Heat Transport regression option has failed when:

    a. pseudo source distance is negative.

    b. absolute value of pseudo source distance is greater than 10 km.

    c. mean error is greater than 4 degrees.

25. This model can be used for simulating water temperature downstream from a reservoir operated to produce peaking power when:

    a. The powerplant operates at a constant release for 24 hours.

    b. The peaking fluctuation is less than 10% of the flow in the river.

    c. The objective of the study is to describe average conditions or bound the range of water temperature fluctuations.

    d. This model cannot be used for peaking because it is a steady flow model.

26. The maximum daily water temperature calculations in SNTEMP suffer from the following problems:

    a. Stream geometry for the node in question is extended upstream without regard to what actually existed upstream.

    b. The program doesn't take into consideration if there is a reservoir, or other discontinuity, less than one-half day’s travel time upstream.

    c. Empirical (regression) coefficients are used to predict the maximum afternoon air temperature used to heat the water.

    d. Travel time variation with discharge is not considered in the model.

27. Water temperature will never reach equilibrium because:

    a. Equilibrium temperatures are always approached asymptotically; temperatures will get closer and closer, but never get there.

    b. Equilibrium temperature is dynamic and always changing.

    c. Both a and b.

IF 312 B Course Evaluation Form - Rip Me Out

Date of Your Evaluation ____________________________

Version of Course Material ____________________________

(If there is insufficient space to answer any question, please attach additional pages.)

PRESENTATION COMMENTS

1. Organization Effective __________ Good _____ Fair _____ Disorganized _____________

Suggestions: ____

2. Clarity Clear ______ Good _____ Fair _____ Obtuse _______

Suggestions: ____

3. Content Complete __________ Good _____ Fair _____ Incomplete ___________

Suggestions: ____

4. Exercises Helpful ________ Good _____ Fair _____ Unhelpful __________

Suggestions: ____

5. Coursebook Excellent Good Fair Poor

a. Comprehensiveness __________ _____ _____ _____

Suggestions: ____
____
____

b. Content Excellent Good Fair Poor

__________ _____ _____ _____

Suggestions: ____
____
____

c. Writing Style Excellent Good Fair Poor

__________ _____ _____ _____

Suggestions: ____
____

d. Graphics Excellent Good Fair Poor

__________ _____ _____ _____

Suggestions: ____
____
____

7. Exercises Excellent Good Fair Poor

__________ _____ _____ _____

Suggestions: ____
____
____

MEETING YOUR NEEDS

1. Personal objectives accomplished: Yes _____ No _____

   Comments on knowledge gained: ____
   ____
   ____

2. Comments on expected utility or applicability of the information gained.

   ____
   ____
   ____

3. Based on the level of information indicated in the following course objectives, rate how well the objectives were met using the following rating table (please use whole numbers only).

1	2	3	4	5
Not met	Fair	Moderate	Good	Fully met

   Course Objectives:

   Rating

   After completing this course, the participative student should be able to:

   a. Understand the theoretical basis for model, including its assumptions and limitations. _____

   b. Be fluent in the stream geometry, hydrology, and meteorology components of the model, and how combining these components creates a stream system description. _____

   c. Understand how to enter data, run, and interpret results from the network and stream reach versions of model. _____

   d. Be capable of calibrating the model given typical constraints, e.g., some data are missing._____

   e. Be capable of using the model to estimate unknown temperatures in a baseline condition and predict water temperatures under altered conditions. _____

   f. Depending on the needs of individual students, he or she will be prepared to either:

1. Conduct a “live” temperature investigation, including how to plan a cost-effective study, gather needed input data, assemble that data into appropriate formats, and display results in a communicative manner; or,

2. Be able to review a completed study, performed by another individual or organization, to assure its quality by critically analyzing it’s modeling components and evaluating the achievement of study objectives.

GUIDANCE FOR THE FUTURE

1. Time Allocation

Please describe what you feel the balance if time spent should be in these areas:

	Average This Course	Average Should Be
Theory	__________	__________
“How To” Description	__________	__________
Hands-On Work	__________	__________
“Biological” Use	__________	__________
Other Explain ______________	__________	__________
	======	======
	100%	100%

2. Length of Course Too Short ________ Just Right ________ Too Long ________

If too short, what should be added; if too long, what should be deleted:

____

____

____

____

3. What prerequisites, if any, should this course have:

____

____

____

4. Other suggestions (e.g., what I liked most, least):

Name (optional) ______________________________

Title ______________________________

REFERENCE

Table R1. POTENTIALLY USEFUL CONVERSION FACTORS

Multiply	By	To obtain
Acre Feet/Day	0.504	CFS
Acre Feet/Month	0.01656	CFS
Acre Feet/Year	0.0013803	CFS
Cubic Feet/S/Day	1.984	AF/Day
Cubic Feet/Month	0.0000003	CFS
Cubic Meters/Month	0.0000134	CFS
Cubic Meters/Second	35.31	CFS
Day	86400.0	Seconds
Degrees Celsius	9/5 C° +32	Fahrenheit
Degrees Fahrenheit	5/9 (F° - 32)	Celsius
Gallons/Minute	0.002228	CFS
Hours	3600.0	Seconds
$J/M^2/Sec$	2.0650596	Langleys/Day
$KJ/M^2/Day$	0.011574	$J/M^2/Sec$
Liters/Seconds	0.03531	CFS
Million Gallons/Day	1.547	CFS
Million Gallons/Month	0.05084	CFS
Months (Average)	2629800.0	Seconds
Years	31557600.0	Seconds
Miles/Hour	.447	Meters/Second
Radians	57.2958	Degrees
Miles	1.609	Kilometers
Feet	0.3048	Meters

Table R.2. Tangents of angles from zero to eighty-nine degrees.

Angle	Tangent
0	0.000
1	0.017
2	0.035
3	0.052
4	0.070
5	0.087
6	0.105
7	0.123
8	0.141
9	0.158
10	0.176
11	0.194
12	0.213
13	0.231
14	0.249
15	0.268
16	0.287
17	0.306
18	0.325
19	0.344
20	0.364
21	0.384
22	0.404
23	0.424
24	0.445
25	0.466
26	0.488
27	0.510
28	0.532
29	0.554
30	0.577
31	0.601
32	0.625
33	0.649
34	0.675
35	0.700
36	0.727
37	0.754
38	0.781
39	0.810
40	0.839
41	0.869
42	0.900
43	0.933
44	0.966
45	1.000
46	1.036
47	1.072
48	1.111
49	1.150
50	1.192
51	1.235
52	1.280
53	1.327
54	1.376
55	1.428
56	1.483
57	1.540
58	1.600
59	1.664
60	1.732
61	1.804
62	1.881
63	1.963
64	2.050
65	2.145
66	2.246
67	2.356
68	2.475
69	2.605
70	2.747
71	2.904
72	3.078
73	3.271
74	3.487
75	3.732
76	4.011
77	4.331
78	4.705
79	5.145
80	5.671
81	6.314
82	7.115
83	8.144
84	9.514
85	11.430
86	14.301
87	19.081
88	28.636
89	57.288

Table R.3. Calendar day to Julian day conversion table.

01-Jan 1
02-Jan 2
03-Jan 3
04-Jan 4
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12-Jan 12
13-Jan 13
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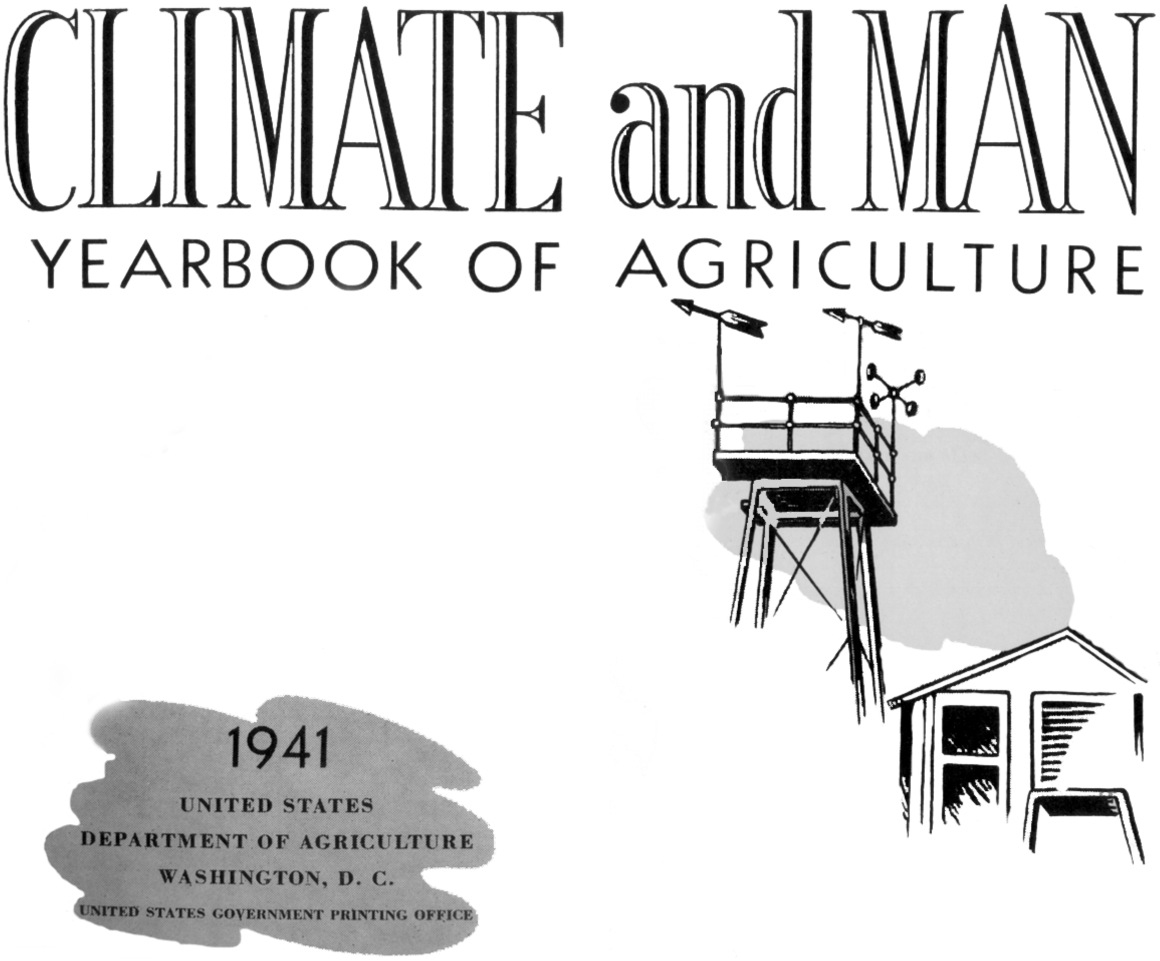


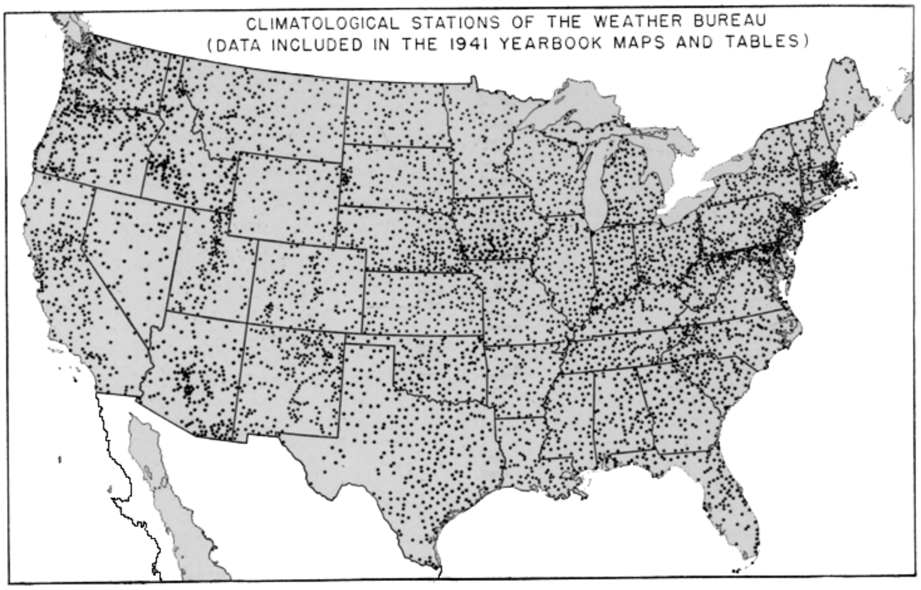
CLIMATE and MAN

YEARBOOK OF AGRICULTURE

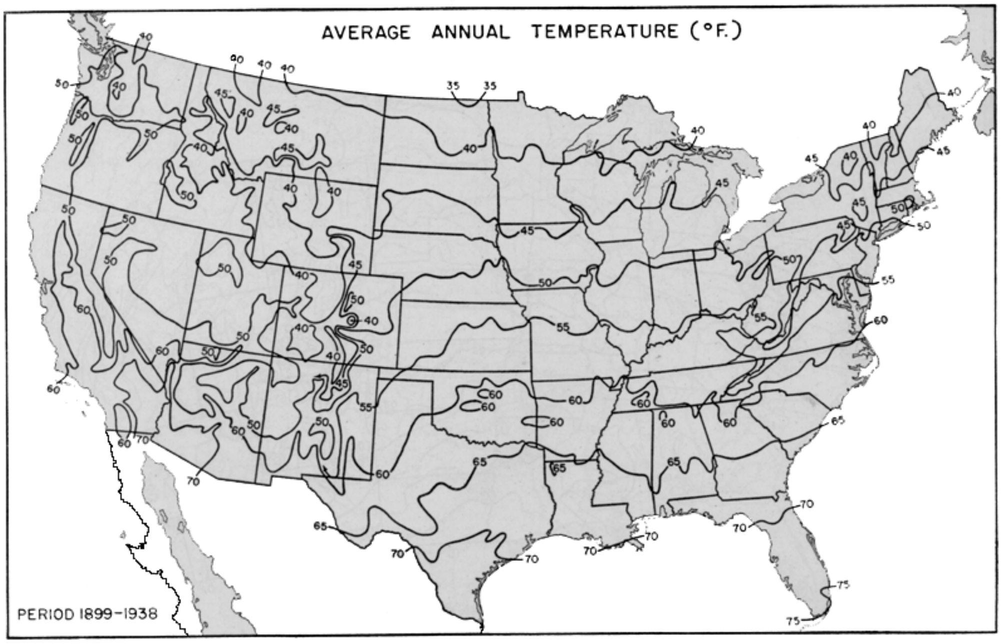
1941

UNITED STATES
DEPARTMENT OF AGRICULTURE
WASHINGTON, D. C.
UNITED STATES GOVERNMENT PRINTING OFFICE

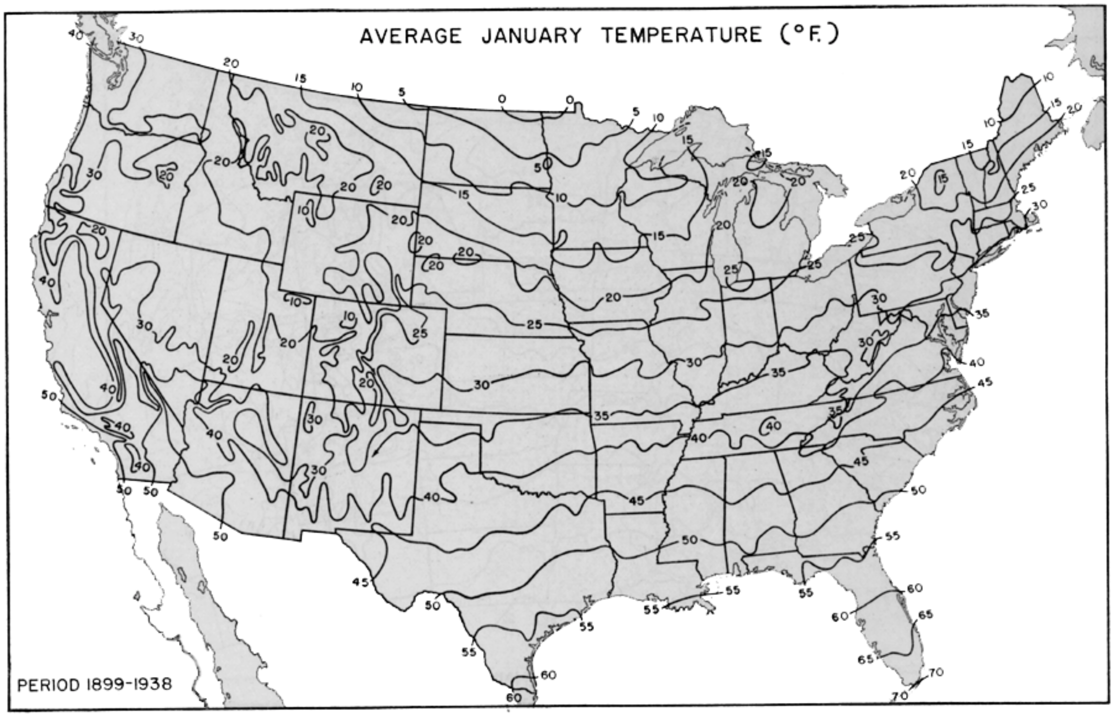
The figures on the following pages are taken from the above reference. Obviously their resolution is crude, but often good enough for certain applications.

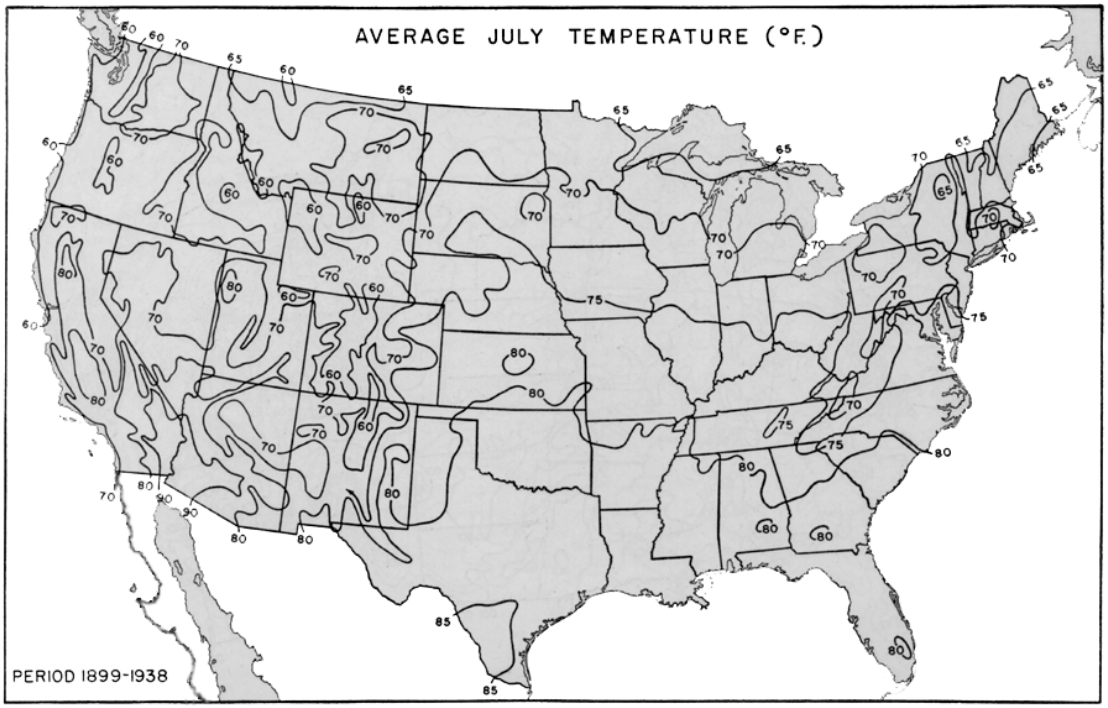


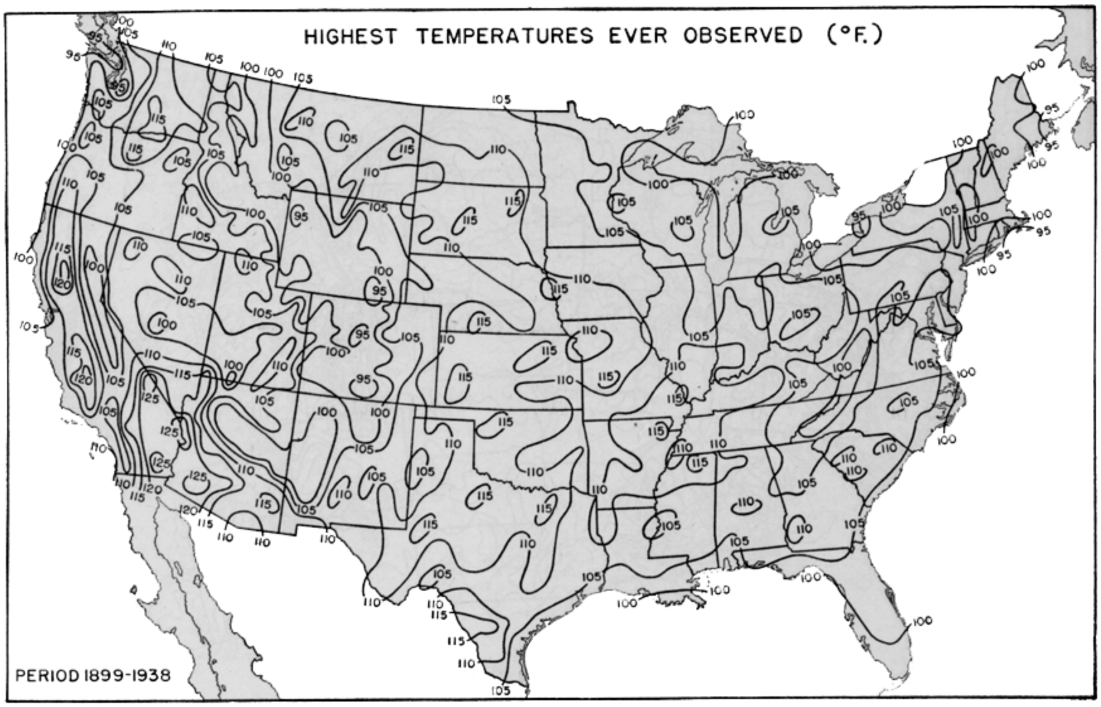
CLIMATOLOGICAL STATIONS OF THE WEATHER BUREAU
(DATA INCLUDED IN THE 1941 YEARBOOK MAPS AND TABLES)

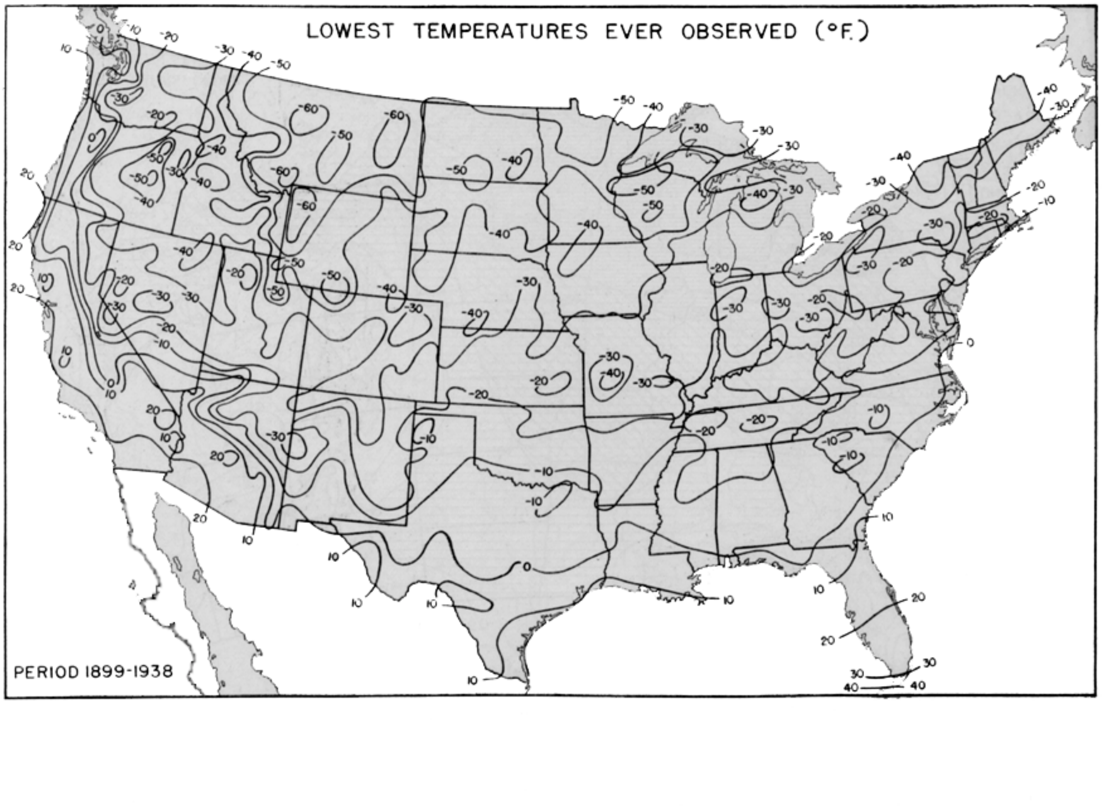


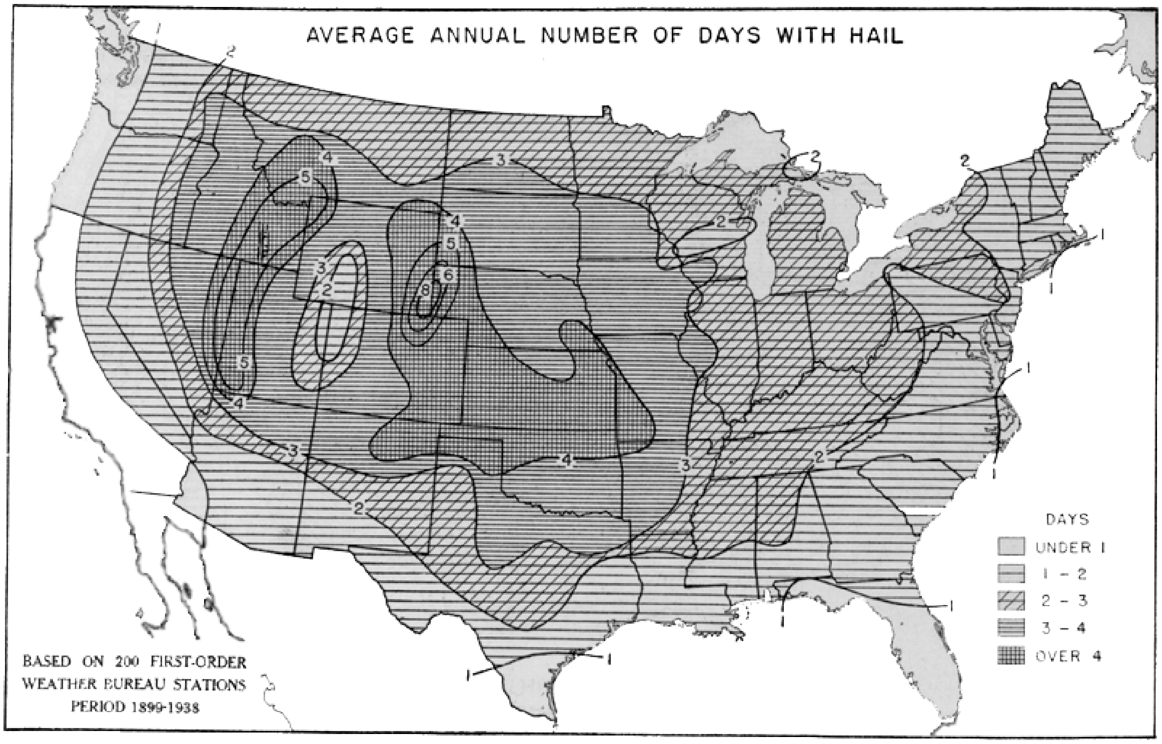
AVERAGE ANNUAL TEMPERATURE (°F.)

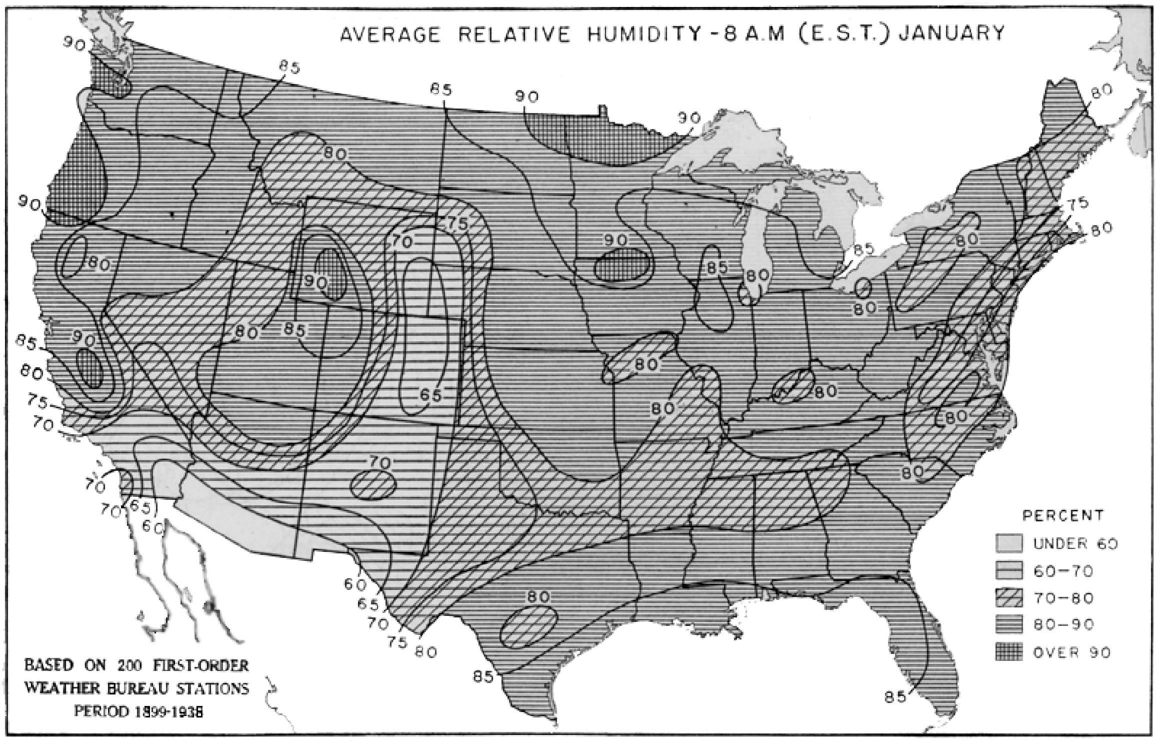

AVERAGE JANUARY TEMPERATURE (°F.)
PERIOD 1899-1938

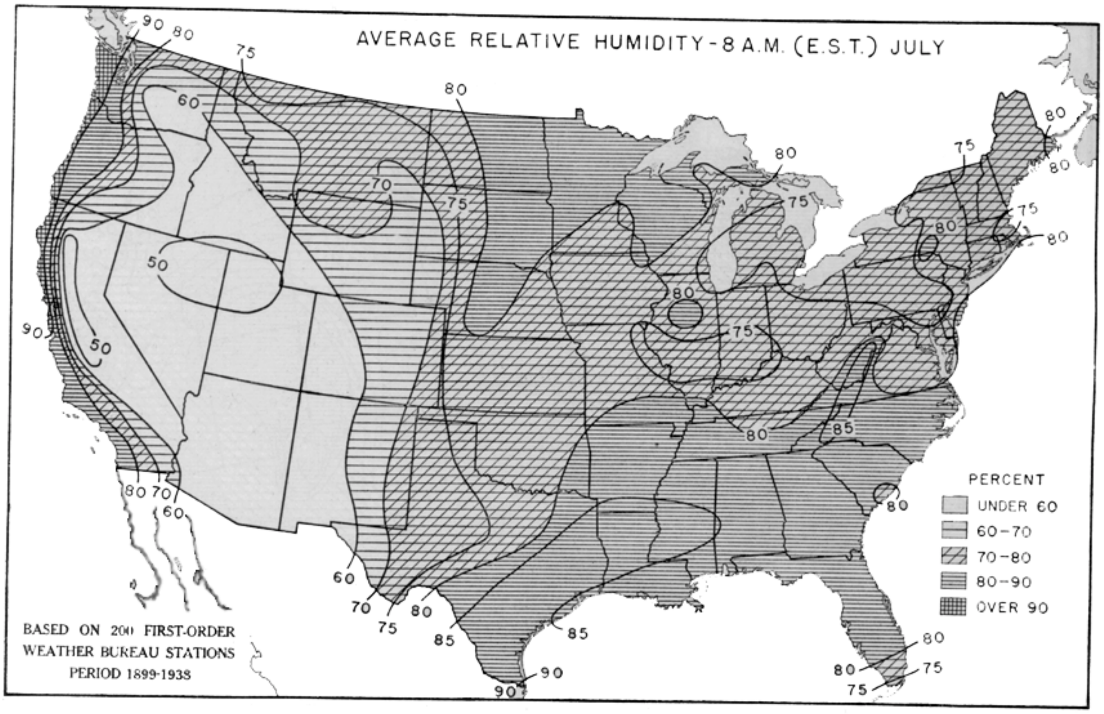

AVERAGE JULY TEMPERATURE (°F.)
PERIOD 1899-1938


HIGHEST TEMPERATURES EVER OBSERVED (°F.)
PERIOD 1899-1938


LOWEST TEMPERATURES EVER OBSERVED (°F.)
PERIOD 1899-1938


AVERAGE ANNUAL NUMBER OF DAYS WITH HAIL
DAYS
UNDER 1
1 - 2
2 - 3
3 - 4
OVER 4
BASED ON 200 FIRST-ORDER WEATHER BUREAU STATIONS PERIOD 1899-1938


AVERAGE RELATIVE HUMIDITY - 8 A.M (E.S.T.) JANUARY
PERCENT
UNDER 60
60–70
70–80
80–90
OVER 90
BASED ON 200 FIRST-ORDER WEATHER BUREAU STATIONS PERIOD 1899-1938


AVERAGE RELATIVE HUMIDITY - 8 A.M. (E.S.T.) JULY
PERCENT
UNDER 60
60–70
70–80
80–90
OVER 90
BASED ON 200 FIRST-ORDER
WEATHER BUREAU STATIONS
PERIOD 1899-1938
90
80
75
60
80
70
75
50
90
50
80
75
80
75
80
75
80
80
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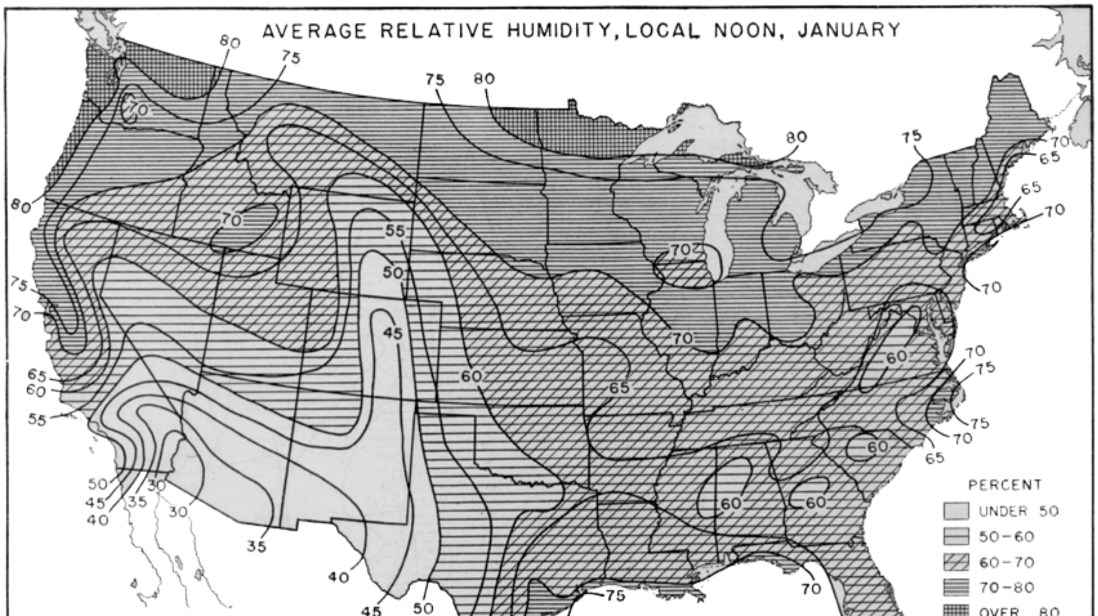
85
90
90
80
80
75
75


AVERAGE RELATIVE HUMIDITY, LOCAL NOON, JANUARY
PERCENT
UNDER 50
50–60
60–70
70–80
OVER 80
BASED ON 200 FIRST-ORDER
WEATHER BUREAU STATIONS
PERIOD 1899-1938
80
75
75
80
70
80
75
70
65
65
70
80
70
55
50
45
70
70
75
70
60
60
65
70
75
75
70
65
65
60
60
60
60
55
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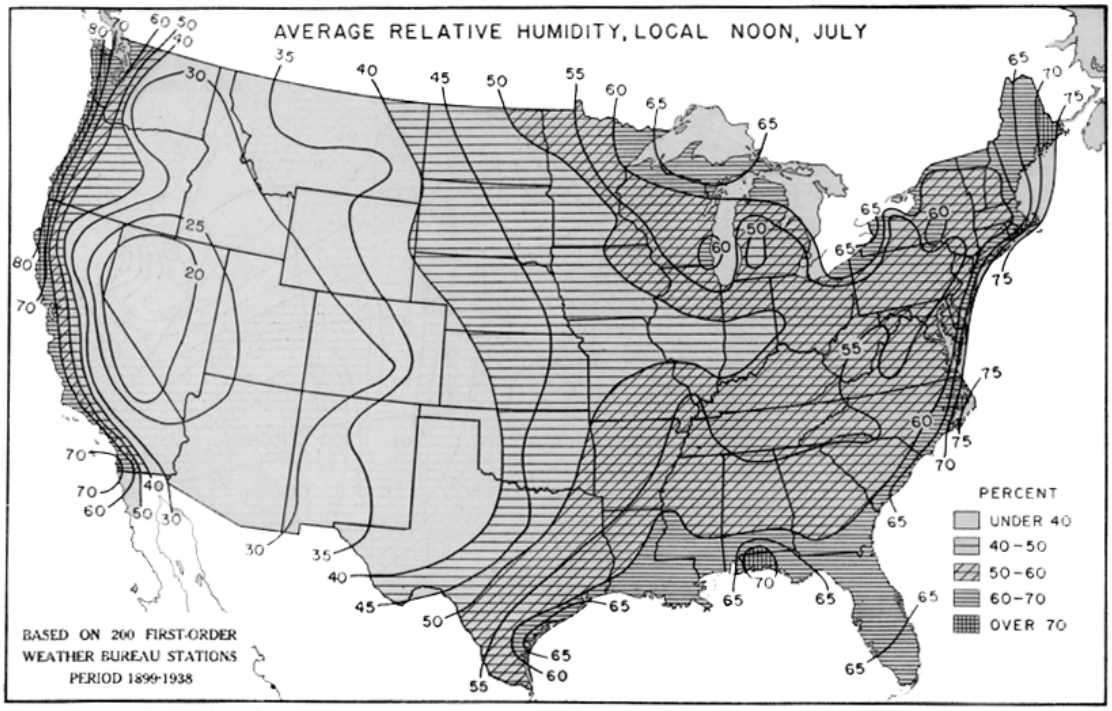
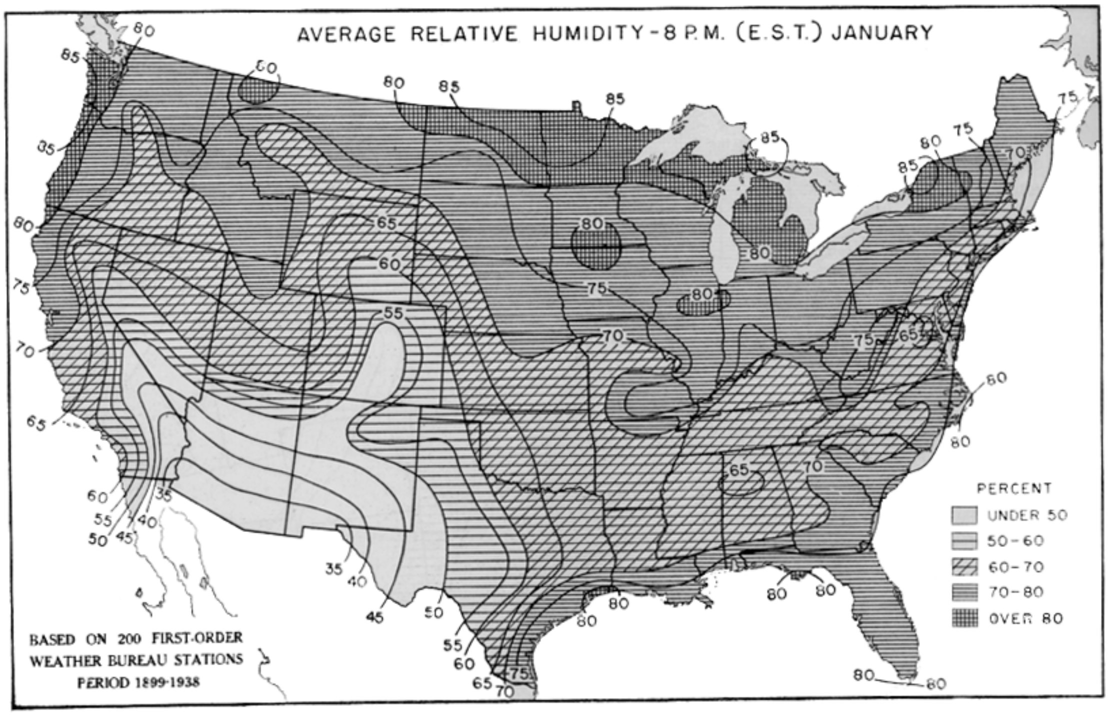
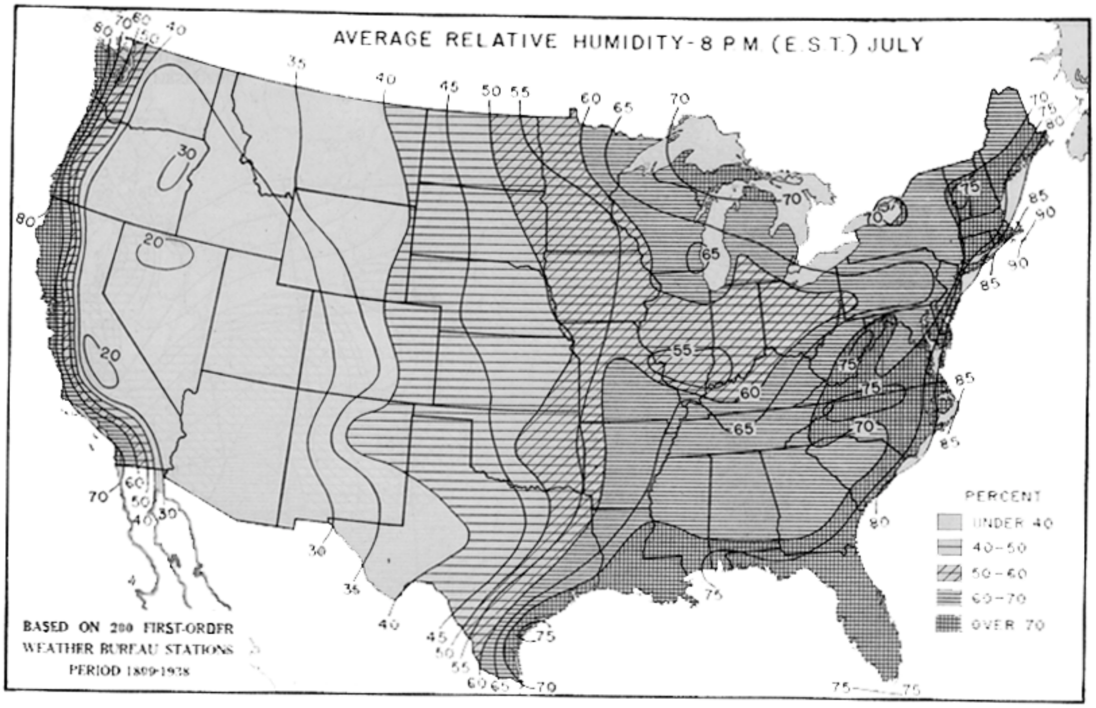
70
70
65

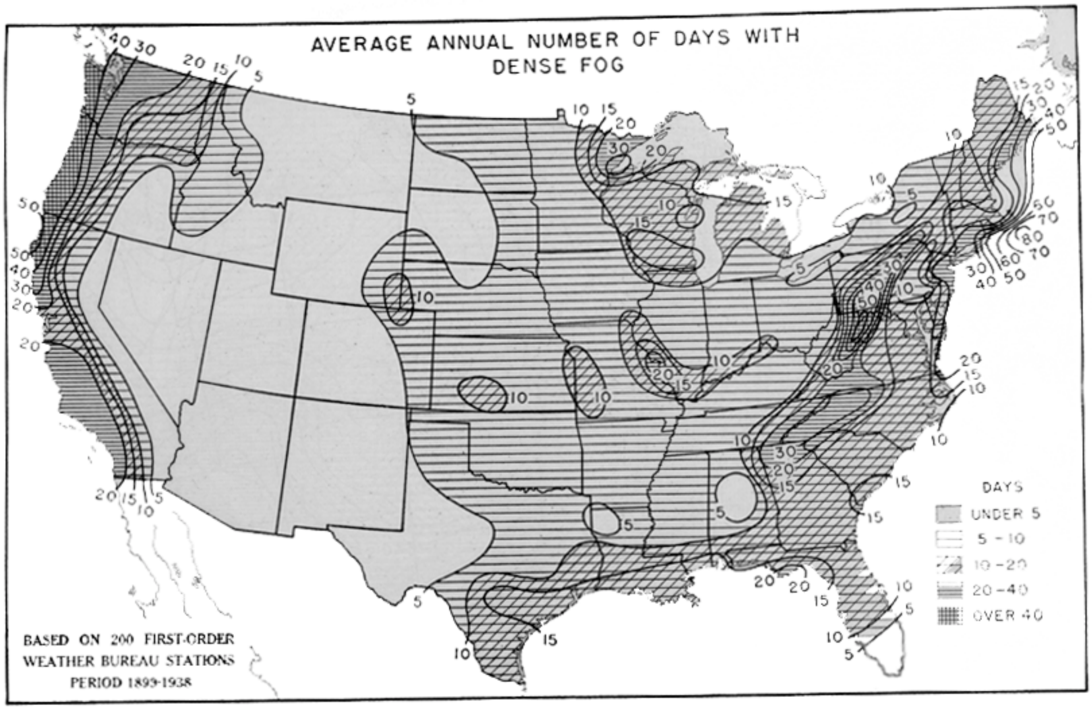

AVERAGE RELATIVE HUMIDITY, LOCAL NOON, JULY

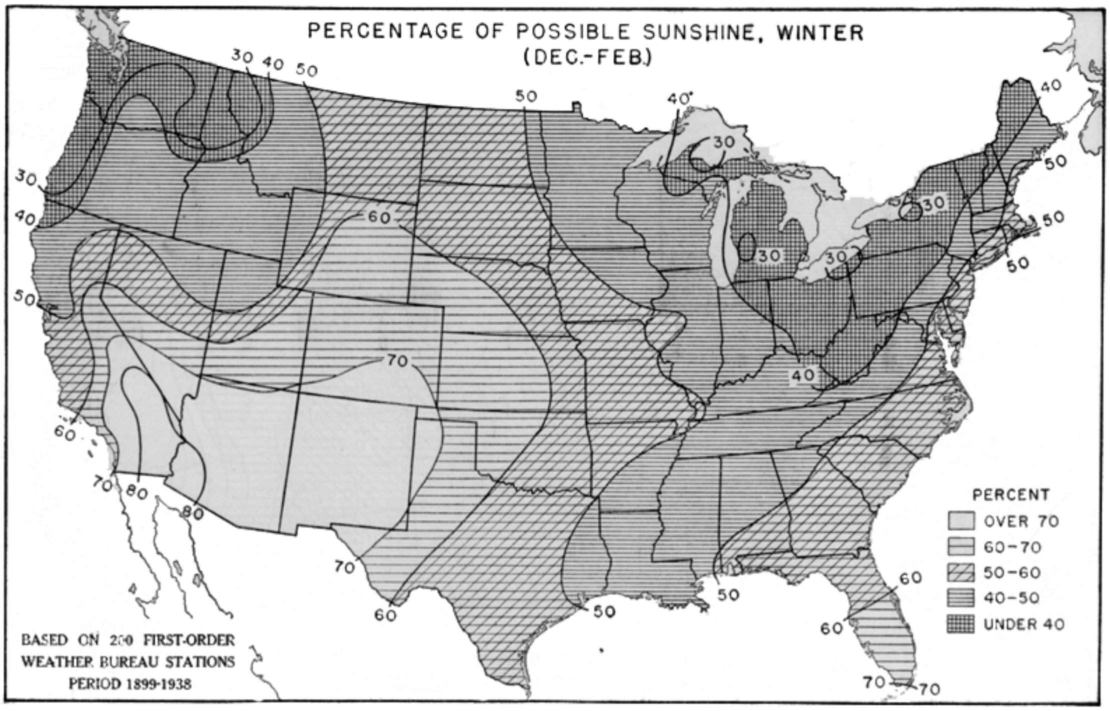
BASED ON 200 FIRST-ORDER WEATHER BUREAU STATIONS PERIOD 1899-1938

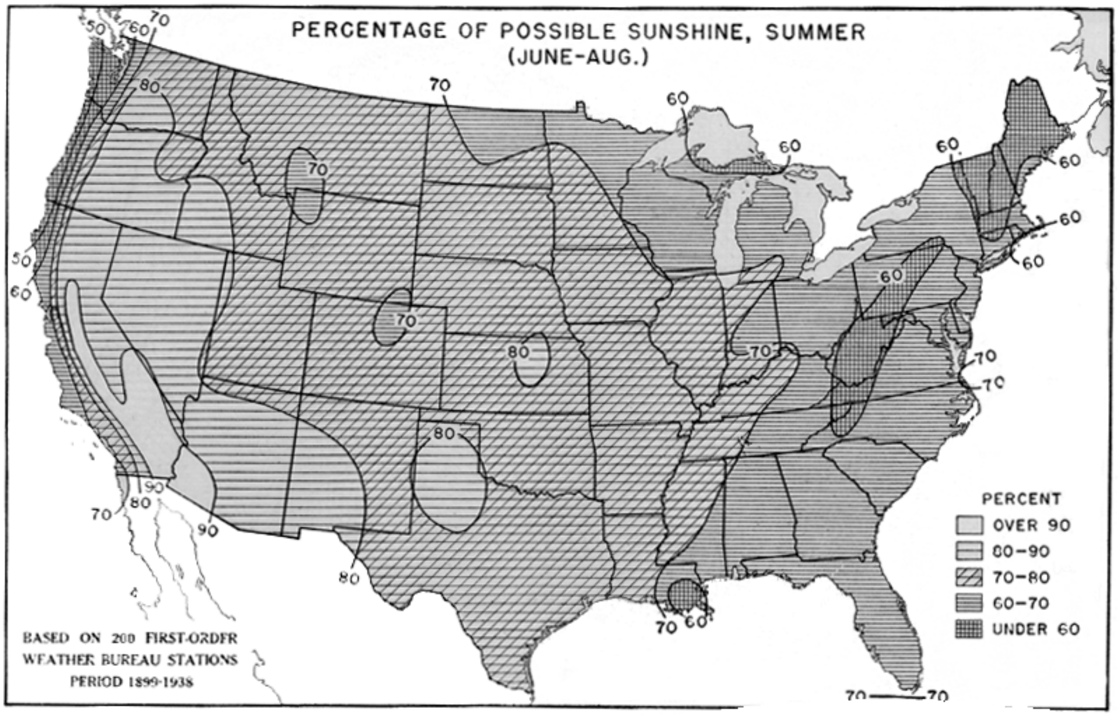

AVERAGE RELATIVE HUMIDITY-8 P.M. (E.S.T.) JANUARY

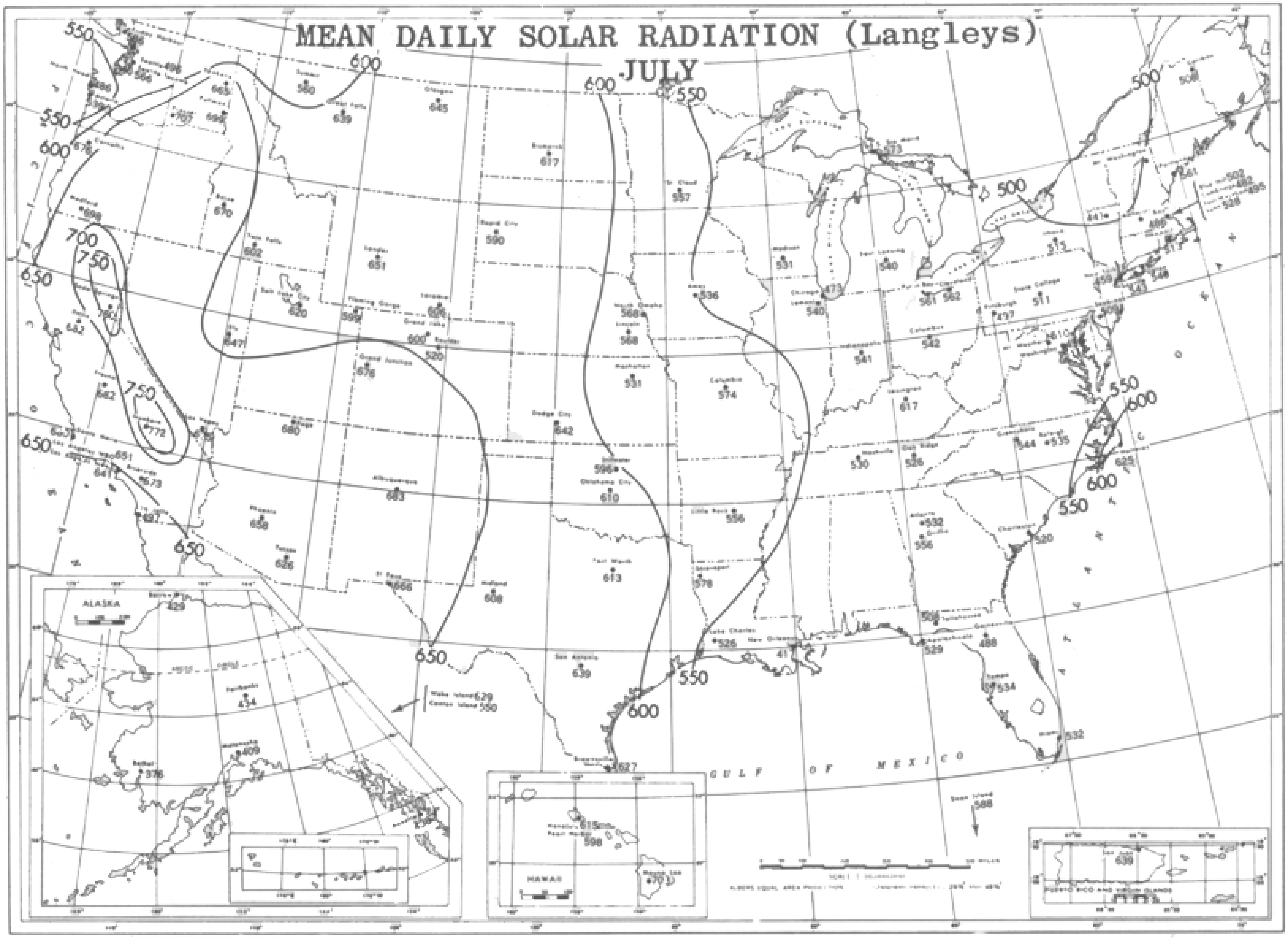
BASED ON 200 FIRST-ORDER WEATHER BUREAU STATIONS PERIOD 1899-1938


AVERAGE RELATIVE HUMIDITY - 8 P.M. (E.S.T.) JULY
PERCENT
UNDER 40
40-50
50-60
60-70
OVER 70
BASED ON 200 FIRST-ORDER WEATHER BUREAU STATIONS
PERIOD 1899-1938
80
70
60
50
40
35
30
20
45
55
65
75
85
90


AVERAGE ANNUAL NUMBER OF DAYS WITH DENSE FOG
DAYS
UNDER 5
5 - 10
10 - 20
20 - 40
OVER 40
BASED ON 200 FIRST-ORDER WEATHER BUREAU STATIONS
PERIOD 1899-1938
5
10
15
20
30
40
50
60
70
80


PERCENTAGE OF POSSIBLE SUNSHINE, WINTER
(DEC.-FEB.)


PERCENTAGE OF POSSIBLE SUNSHINE, SUMMER
(JUNE-AUG.)



MEAN DAILY SOLAR RADIATION (Langleys)
JULY

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Biological Guidance and Criteria:

Armour, C. L. 1991. Guidance for evaluating and recommending temperature regimes to protect fish. U.S. Fish and Wildlife Service Biological Report 90(22). 13 pp.

Sample Application:

Bartholow, J. M. 1991. A modeling assessment of the thermal regime for an urban sport fishery. Environmental Management 15(6):833B845.

SNTEMP-specific References:

Bartholow, J. 1995. The stream network temperature model (SNTEMP): A decade of results. Pages 57B60 *in* Ahuja, L., K. Rojas, and E. Seeley, editors. Workshop on Computer Applications in Water Management, Proceedings of the 1995 Workshop. Water Resources Research Institute, Fort Collins, Colorado. Information Series No. 79. 292 pp.

Biological Effects Summary:

Coutant, C. 1976. Thermal effects on fish ecology. Pages 891B896 *in* Encyclopedia of Environmental Engineering, V2. W&G Baird, Ltd. Northern Ireland.