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ABSTRACT

The objectives of this geography course for liberal arts students include the following: 1) to demonstrate cooperative action among sciences, by showing that physical and chemical phenomena occur at biological surfaces that usually exist in economic and cultural frameworks; 2) to show that laboratory principles of mass and energy exchange and transformation can be used in understanding urban, rural, and wildland parts of the earth's surface; and, 3) to lead the student to examine his ideas about environment and the earth using the budget accounting model of relationships which help describe regularities in regional landscapes and economics, and aid in examining man's role in changing the conditions that affect the processes forming landscape features. The flexible sequence of teaching units examines the simpler individual budgets first: 1) wind, one week; 2) atmospheric composition and pollution, one week; 3) energy exchanges in ecologic and economic systems, radiative energy, and heat, two weeks; 4) water exchanges at the earth's surface, two weeks. The interacting, complex combination of these budgets are examined in the last four synthesizing units; 5) organisms, one week; 6) ecosystems or elements of the landscape, two or three weeks; 7) mosaic landscapes, one week, and, 8) regions and their world pattern, two or three weeks. The objectives suggested outline of topics, relation to other units, extensive useful references, and case studies are cited for each unit. (Author/SBE)

A SURVEY COURSE

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The Energy and Mass Budget at the Surface of the Earth

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A SURVEY COURSE: THE ENERGY AND MASS BUDGET AT THE SURFACE OF THE EARTH

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19 March 1968

RATIONALE AND OUTLINE FOR THE COURSE

This is a course about the earth's surface—at once the focus of geography and the field of action of many other sciences, biological and physical, and the scene whereon still other sciences, like economics, act out their roles. In this course we look at this interesting and peculiar surface, the interface between earth and atmosphere, in terms of the streams of energy and matter that come to it and leave it, are transformed at it, and themselves influence natural and cultural phenomena at and near it.

Objectives:

The objectives of this course include the following:

To demonstrate cooperative action among sciences, by showing that physical and chemical phenomena occur at biological surfaces tnat usually exist in economic and cultural frameworks.

To show that laboratory principles of mass and energy exchange and transformation can be used in understanding the functioning of urban, rural, and wildland parts of the earth's surface.

To illustrate application of the dictum that "climates owe their individual characteristics to the nature of the exchange of momentum, heat, and moisture between the earth's surface and the atmosphere" (Thornthwaite).

To indicate how certain energy and mass budgets characterize regional landscapes and economies, as, for example, soil moisture as a product of the energy and water budgets characterizes and dominates life of the Great Plains or the Waikato Valley of New Zealand.

To lead the student to examine his ideas about environment and the earth, and to see what general validity they have when set into a budget-accounting frame.

The student who makes a budget analysis should become more aware of the earth's surface, so close and often so ignored, as a place where conflicts and divisions continually occur and where physical laws are worked out and chemical reactions take place. We want him to use "models of relationships. . .which help describe regularities in landscape features,"[1] the model proposed here being the budget accounting of mass and energy.

His new skill in describing regularities can be employed in examining man's role in changing the conditions that affect the processes forming landscape features. He can then foresee some of the results of human activity, either purposeful activity in regional development, or inadvertent activity, and develop "a disciplined view of the earth's surface as it changes."[2]

In another kind of extrapolation, the student should be able to employ the budget model to state the "complex of landscape features he would expect to find on any given part of the earth's surface."[3] He should end with more concrete ideas of the diversity of the earth and how it can be measured and explained. Climate as expectation can be expressed in terms of flows of energy and matter, and the student should be able to apply this analysis to other seasons of the year, other centuries, and other parts of the world, to visualize what things are like in other places and at other times.

1. Association of American Geographers. Commission on College Geography. *Geography in Undergraduate Liberal Education*. Publication No. 1, 1965, p. 16.

2. *Ibid.*, p. 24.

3. *Ibid.*, p. 16.

RATIONALE

Field disciplines coordinate with geography also use and contribute much to budgeting concepts and techniques. The biological sciences, with their emphasis on ecosystems and the energetics of communities, show how the vegetation-covered sections of the earth's surface respond to and transform incoming streams of energy and matter. Research in the applied biological fields of ecology, agronomy, and forestry enters the course at many points, as does work from oceanography and glaciology, at surfaces that are not primarily biological. As meteorology becomes more concerned with boundary fluxes that affect the whole troposphere, it also contributes through special investigations to an understanding of processes and budgets at the underlying surface.

Many land surfaces are culturally and economically infused. Phenomena at these surfaces obey physical and chemical laws, but cannot be fully understood without recognizing the cultural nature and origin of the surface, and the often economically-determined vegetation that covers it, even in so-called wild lands. Climate as an integration of the mass and energy budgets is usually seen in a cultural landscape,[4] and its influence on that landscape is well expressed through the budget concept.

The geographic theme of research on physical phenomena at the earth's surface runs through the course, which is oriented not to atmosphere or substrate but to their interface. Other geographic themes appear in parts of the course: Relations of man to land enter into discussions of productivity and man's modifications of surface and atmosphere. Spatial relations are illustrated in the local transports of heat and moisture among the elements of a mosaic landscape or in the long-distance advections that link regions remote from one another. The theme of areal association of budget processes within specific places and areas integrates materials in the entire second half of the course.

A fruitful antithesis in many subjects is found in the opposition of local and world viewpoints. We can ask this question about any section of the earth's surface: Are the local forces, which include solar radiation locally converted, stronger or weaker than external forces? How self-sufficient or autonomous is this corn field or that glacier? How do the relative strengths of local and external forces change with the hour or season? The synthesis of budget processes proceeds in the second half of the course from small-scale to global, for a surface of each scale of size has a different way of working out its balance between local and external forces. These forces can in each case be expressed in quantitative terms of mass or energy. Differences in interaction at surfaces of different size illustrate these connotations of changing scale.

Interactions among atmospheric conditions, vegetation, soils, land form, and water in the landscape, furthermore, are best expressed through the mass and energy budgets. The influence of vegetation on local and micro-climate can be worked out quantitatively through the budgets, as can the impact of rainfall and large-scale atmospheric advection upon the vegetation. And so with development of land form and bulk water in channels and lake basins. All are intimately related to the water budget as it is conditioned by the energy budget. Soil climate and soil formation are products of storage of energy and water in it, and these storages are consequences

4. I have expressed this view at greater length in "Geography, physical and unified," in the *Professional Geographer* 17, No. 2: 1-4, 1965.

of the budget of energy and water at the earth's surface. In turn, the storage capacity of the soil affects that surface budget. Aspects of economic geography are connected with climate as expectation, a connection that can be traced back to our perception of the energy and water inputs into the local budget. Local climatic characteristics regarded as "innumerable local variations of the flux of energy"[5] illustrate the pervasive significance of the energy and mass budget that has guided the writing of this course and that, I hope, will add to the student's appreciation of the functioning of the surface of the earth.

The Outline:

This course has been outlined for liberal-arts students who are reading climatology during one term only. It assumes that they have had some work in a basic science, and it holds back no interesting ideas for possible use in some later course. In this premise, it continues what I have tried to do, less explicitly, in presenting a sequence of topics to students at Berkeley, Milwaukee, Newcastle, N.S.W., and Madison over the past seven years. Many topics are concepts that have been found useful in research and therefore seem to have a special immediacy to many students; other topics fill out the theoretic framework implied by budget accounting methods; still others connect the results of the budgets to biological and economic productivity, in their temporal and geographic differentiations.

Systems at the surface of the earth can be examined in different ways, one of which is to balance out the flows of matter or energy through them. As examples, some systems of the overall, world-wide man-land supersystem can be presented, as follows:

a. Water flow through the soil-plant-atmosphere system in general terms, and in specific agricultural sites in particular;
b. Inputs of water and solar and advected energy to a Danish grassland, and the resulting yields of sensible and latent heat, and ground water, and of grass as basis of a national economy;
c. Seasonal change in soil-moisture probabilities as a resultant of evapotranspiration and the spacing of rains, and as the basis for management decisions in a grass-conversion economy in New Zealand;
d. Soil moisture of an Iowa corn field as a resultant of the water and energy budget of the plant community, and its consequences for yield;
e. Heat and water budgets of wheat land in the Ukraine, and their modification by such measures as shelterbelts, irrigation, and snow management;
f. Partition of energy incident on desert scrub and irrigated cotton in middle Asia;
g. Heat, water, and salt balances of a desert animal—the merino sheep;
h. Energy flow in a marsh ecosystem with its fauna;
i. Energy from the sun moving in other forms through a snow-covered upland basin that yields melt-water for lowland irrigators;

5. Association of American Geographers, Commission on College Geography. *Geography in Undergraduate Liberal Education*. Publication No. 1, 1965, p. 171.

j. Rain-water flow over and through the slopes and in the channel network of a headwaters drainage basin;
k. Input of water, nutrients, and sediment to a flood plain;
l. Sediment and water exported from suburban construction sites in Megalopolis;
m. Sulfur flow in a metropolitan region—arriving by the trainload, leaving through diffusion in the urban atmosphere;
n. Energy and mass budget of Antarctica and of the Arctic Ocean.

These systems all exemplify the ideas that the landscape is a functioning entity, that the inflows and outflows of energy and matter to and from it are measurable, and that they can be brought into a single framework if we cast a budget in terms of calories of energy and grams of water or other matter. If our interest lies in a particular outflow, this can be determined by establishing the other components of the budget. For instance, the hour-by-hour changes in melt-water runoff that comes from an upland basin in the crest region of the Sierra Nevada can be specified quite accurately from data on its relief and vegetation and on current conditions of upper-air flow that determine hourly values of the energy budget at the basin surface.

Liberal-arts students may be interested in engineering results of budget accounting chiefly because they are curious whether they work or not, but their interest in budget accounting that impinges on subjects of current concern is likely to be more lasting. Many students are concerned about productivity of the biosphere and yields of food for human nutrition; the quality of life in the presence of massive urban energy-conversion processes; the pollution of urban and even national atmospheres, and of water bodies, with degradation of recreation and amenity; how to manage resources and reach decisions between alternative investments in national or regional enterprises; repercussions when the solution of one problem disrupts other systems, and makes them undergo unexpected and perhaps irreversible changes. Students are also interested in the way these ideas of productivity, resource management, and quality of life are experienced elsewhere in the world.

Sequence of Teaching Units:

The sequence of teaching units in the course that is suggested in the following pages is one of several possible orders that the teacher may adopt. As one reviewer noted, the outline has an accordion nature that allows lengthening or shortening any specific parts. The commentary on each unit contains suggestions to help the teacher in working out a schedule of priorities among topics in that unit that he may emphasize or shorten. The sequence of units presented in the following pages is the one that seems best to the author, for reasons that are stated in the commentary on each unit, in which the transitions and connections of that unit with those earlier and later are discussed. This sequence is as follows:

A short introductory unit on budgets of the city (optional) . . one day

Systematic Units

I Atmospheric motion near the earth's surface. . . . . . one week
II Exchanges of matter (except water) at the earth's surface . . . . one week

III	Exchanges of energy at the earth's surface	two weeks
IV	Exchanges of water at the earth's surface.	two weeks

Synthesizing Units

V	Synthesizing the energy and mass budgets of organisms	one week
VI	Synthesizing the budgets of elements of the landscape	two or three weeks
VII	Synthesizing the budgets of mosaic landscapes.	one week
VIII	Synthesizing the budgets of regions into the world pattern	two or three weeks

The rationale of this sequence lies in examining the simpler individual budgets before attempting to see how they are associated areally at places on the surface of the earth. The individual budgets of energy, water, and so on are more easily visualized by students than is their interacting, complex combination. Most of the suggestions by reviewers about varying the sequence of units had to do with changes within the first group, Units I to IV. Some considered systematic study of energy and water more important than study of wind (Unit I) or atmospheric composition (Unit II), and suggested they might be taken up first. Unit I, which contains material on the global wind belts as well as on local impacts of wind, is so placed in order to prepare the student for the global moisture and energy transports that enter into Units III and IV. However, if the world-wide circulation of moisture and energy in the atmosphere were deferred until the end of the entire course, it could be taken up along with the world-wide distribution of the water and energy budget at the surface of the earth, which closes Unit VIII.

Other reviewers suggested that the order of the systematic units be energy—wind—water. Pollution (Unit II) would be left to the end of the course as representing, because of the intensity of man's influence, the most complex subject. It seems generally advisable to take up water budgets after energy budgets, because evapotranspiration is an immense energy-converting process that is difficult to understand until the student has some idea of how it is limited in specific times and places by inadequate supply of energy.

This choice about Unit II depends to a degree on whether or not the teacher wants to confront his students initially with a problem in the environment of man and to apply their interest in this problem to lead them into thinking about the environment per se, with its exchanges of matter and energy at the earth's surface. Many of the surface processes considered in the course take place in a framework that is fundamentally a cultural one inasmuch as a large fraction of the earth has been modified by man in ways that affect the exchange processes. These processes also may lead into such questions as agricultural production or irrigation, or, in particular, the release into the air of sulfur or nitrogen oxides, which are certainly of cultural origin. The pertinent question for the teacher is whether it is advantageous for the student to approach geographic reality from an initial interest in the human condition. Some students need no such orientation, but are interested from the outset in what the earth is like and how it works. The teacher knows his own students and can decide best which approach will seem most relevant to them.

OUTLINE

The course might be used over two terms, if desired, with the systematic units (I through IV) in the first term and the synthesizing units (V through VIII) in the second. Most of the necessary additions could be drawn from the lists of suggested references and from further sources cited in critiques and other general reviews, such as those listed in the first sections of references, especially in Units III (energy) and IV (water). Further expansion might well go in the direction of more thorough case studies of these ecosystems, agricultural systems, and cities for which adequate data are available in cited sources. The expansion might be either toward a more complete working out of energy or water budgets as they change over the year or between land-cover types, or else toward an economic evaluation of the production functions of a landscape. For example, the yields of wood, forage, recreation, and water for irrigation and power from a mountain basin can all be given financial values that, although crude, illustrate the relative contributions each kind of production makes in the values of our culture. Such an extension could be carried further into descriptions of regional production, its internal geographic organization, and its external spatial relations. In this way students can be introduced to many more of the economic and cultural themes of geography than can be done within one semester, and see more deeply into the fascinating interactions among physical, chemical, biological, and cultural forces.

The course might, on the other hand, be abbreviated by shortening those units that seem least closely associated with the water-energy theme which is developed systematically in Units III and IV and areally chiefly in Units VI and VIII. Ways in which other units might be shortened without losing topics relevant to the water-energy theme are suggested in the commentary on each unit. In some cases, the bridge topics can be presented by lecture rather than development in order to save time. In shortening Unit II, for example, the instructor should retain time for one of man's most important roles in changing the earth—producing urban atmospheres. The problems presented by these atmospheres suggest connections with the social sciences and the present nation-wide concern with quality of the environment and quality of life. In shortening Unit VII, to take another example, the instructor should retain discussion of drainage basins as assemblies of slope facets or ecosystems that are unified by the movement of water—a concept already familiar to students.

It is hoped that many instructors will find some of the outlines and references here offered useful within their existing courses. This seems most likely with respect to the material on water. Hydrology and water resources should play a more important role in geographic education than they now do, not only because hydrologic processes give us a way to see the earth's surface as a whole, but also because there is concern with water supply and water quality, as our population presses on a resource that only recently was considered ample and free.[6] However, segregating material on water alone tends to reduce the focus on the peculiarly geographic theme

6. The increasing acceptance in geography curricula of the study of hydrology and water resources leads me to a further optimistic hope: namely, that at some future time such acceptance will obtain also for the geographic study of energy. By "energy" I refer not only to transport of oil and coal, but to *all* forms occurring in biological, economic, and climatological systems. A call to action already has been sounded by several geographers; see papers cited in section B of references for Unit III.

of areal association. All through the course as outlined, this theme occurs in example after example of the joint occurrence and interaction of energy and water phenomena at specific places on the surface of the earth. One teacher experimenting with a course like the one outlined here reported difficulties when he entirely omitted work on energy considerations. Each teacher should consider carefully whether the benefits of a sequence solely on water in landscape and society, far-reaching as it may be, would outweigh those of an examination of water and energy in areal association.

Little needs to be said about the sequence of teaching units in the synthesizing portion of the course, that is, Units V through VIII. These are arranged in the direction of increasing scale, and no other possibilities were suggested. More or less time, of course, could be devoted to any level of the four. Usable case studies are cited for each level in sufficient numbers for considerable expansion.

A short description of each teaching unit of the course follows. Later pages present the objectives of each unit, a suggested outline of topics in it, comments on the unit in relation with others, and useful references.

Summaries of Teaching Units:

An introductory unit on the city. As a locus in which ideas of input and output of energy, water, and other forms of matter can be introduced to students, the local city has many advantages due to its familiar nature. Students already know that it receives rainfall and piped water, and yields outflows from its water budget through evaporation from lawns and parks, and runoff through the network of sewers. They also are aware that it balances its energy budget at a high level by importing fossil fuel and that here man's modification of surface and atmosphere is most radical.

Unit I. Wind. A brief description of the circulation of the atmosphere and the secondary motion systems of low and of middle and high latitudes leads, through consideration of the layered structure of the lower air, to the impact of moving air on the earth's surface, specifically on its vegetation and soil, and man's structures. The transporting role of air streams also is foreshadowed.

Unit II. Matter Other than Water. Atmospheric composition is examined from the standpoint of its dependence on effluxes from the underlying surface, which can be expressed in budget terms. Examples are the contributions to the atmosphere from the biosphere in times past and from cultural landscapes in the present. Air pollution affords scope for discussing not only chemical and biological, but also economic and political processes, often, regrettably, from local examples.

Unit III. Energy. This unit begins with a general discussion of the central role of energy in biological and geographical systems at the earth's surface. This role can be illustrated by the equivalence of the forms of energy in radiative and atmospheric conditions in nature, in vegetation, and in our industrialized economy. Thereafter the individual fluxes are taken up. First is radiation, easiest for the student to visualize, along with surface albedo. The radiation budget enters into the total energy budget, which shows how available energy is partitioned at the earth's surface into downward and upward fluxes. The flux into the substrate is linked with storage capacity, particularly in water bodies, that looks forward to the dichotomy of continental and marine budgets in later units. Sensible-heat flux into the atmosphere is linked with the warming of the air and the resulting regime of air temperature.

OUTLINE

Unit IV. Water. After discussing the general idea of the water budget with its income, storage, and outgo, the unit takes up the latent-heat flux, or evapotranspiration, which is a major result of the energy partition noted in Unit III. Evapotranspiration humidifies the lower air, and a discussion of the local cycling of water leads into the topic of vapor transport into and out of a given space (North America). Motion systems that abstract water from this vapor flow display extreme variability, which is reflected in the irregular delivery of water to the earth's surface. Infiltration of water into the soil enters the soil-moisture budget, where this unit ends; overland flow and groundwater outflow are included in Unit VII.

Unit V. Budgets of Organisms. Organisms convert energy, water, gases, and solutes into new forms. The budgets of each of these quantities are often intimately associated and display various kinds of influence upon one another. To this point considered separately, the budgets now can be seen in their joint working, i.e., their areal association. Such trade-offs among budgets as avoidance of heavy heat loading in order to conserve water, show how the interaction among them is governed in a degree by the organism itself, whether plant leaf, animal, or man.

Unit VI. Ecosystems. Study of combined mass and energy budgets at leaf surfaces prepares the student for budgets of plant communities. These have income and outgo accounts, internal circulations of energy and matter, and a resultant biological productivity, a subject that brings in several disciplines and touches on the overriding problem of human starvation. Data on these questions will increase as the IBP continues, though the unit does not attempt to list all the plant communities of the world. Rather, it is built around case studies of ecosystems that include budgets of energy and water, and often of other forms of matter. Such non-biological surfaces as glacier snow-fields and lakes, where the principal interest is in the mutual interaction of the energy and water budgets by themselves, supplement the ecosystem cases. For convenience, these surfaces and ecosystems are given the general name of landscape element, i.e., elements of the visible scene.

Unit VII. Mosaic Landscapes. Assemblages of different ecosystems, slope facets, or other landscape elements into mosaic landscapes are introduced in this unit as a bridge between ecosystems and areas of regional size. The different parts of a mosaic receive similar inputs of water and energy, but transform them differently. These contrasting budgets within a mosaic are linked through local movement of energy and mass in the local air and along the earth's surface. For example, flows of sediment-laden water from upland slopes into stream networks link uplands and flood plains. This example suggests that flood plains, as vulnerable, productive pieces of land, present interesting economic as well as hydrologic problems.

Unit VIII. Regions, and Their Global Patterns. At the scale of this unit, large-scale advection of moisture and energy by air streams unifies extensive areas of the earth's surface through similar inputs of energy and water. Such regions also are unified by similar environmental deficiencies or problems that evoke programs of regional development. Case studies of regional budgets, their variations in time, and some of their implications for economy and society show many aspects of geographic problems at this scale. Water budgets are important in proposals for regional investment in the United States and the Soviet Union. Physical budgets themselves are important in the polar lands and over regions of the oceans.

Seasonal change and secular change, with their implications for regional economies, follow from regional budget accounting. Finally, regions can be grouped by land masses or latitudinal zones in order to lead the student to see salient patterns of the whole world. From this point he can look back to the wind belts of Unit I, the world radiation patterns of Unit III, the patterns of high evapotranspiration or precipitation of Unit IV. This poses the final question—how does the areal distribution of climatic budgets over the whole earth display the different influences of substrate, solar radiation, and atmospheric circulation in interaction?

Conclusion:

This final question illustrates the value of budget bookkeeping in formulating fundamental problems, and recapitulates earlier applications of the budget to explain phenomena at the scales of regions, landscapes, and ecosystems. It demonstrates that many questions are not easily approached through one discipline alone. Solutions require cooperation of several disciplines and a recognition of the unity of science and the unity of the earth's surface.

The student is reminded that he has now re-examined in a deeper frame of reference some of his initial ideas about the environment of wildlands, cultural and urban landscapes, the atmosphere near the earth's surface, and the surface itself. Study of the transactions of energy and matter has given him a means of recognizing the intertwined workings of the processes at and near the surface and their connections with human institutions.

References:

Since no textbook is yet available to provide basic teaching materials on the set of ideas to be discussed in this course (although one is in preparation and has had preliminary trials in Australia), it is necessary to provide references to papers containing examples of the budget approach and discussions of its implications. Such references have been assembled for each teaching unit. Many papers would be useful in two or three of the teaching units, and have been cross-referenced.

References are offered in numbers sufficient enough to provide each teacher with a wide range of choice. Certainly no instructor will read all or even half of the references cited, but he will have opportunity to choose those that seem most useful to him on the basis of brief annotations. Availability of many papers should make for great flexibility in the way the course will be taught. The references include many case studies, since to many students nothing is quite so convincing as being able to work out the numbers in a new concept or method, and see that the idea really does hold water. Such trial balances are very common, in keeping with the budgeting emphasis of the course.

Few references not in English have been listed for students. If a teacher wishes to pursue further an especially good set of studies, like those on timberline land management in the Austrian Alps, he can do so from the references in the one or two English-language papers cited from the bibliography of that program or in review articles.

One exception to the practice of cross-referencing should be mentioned. The papers immediately below are cited here without regard to whether they might also be cited in one of the teaching units, because they are highly significant for an initial understanding of budgeting ideas in geography. The same is true of citations in the optional unit on the city.

1. Ackerman, E. A. "Where is a research frontier?" Annals of the Association of American Geographers 53: 429-440, 1963. [As major subsystems at the earth's surface, the budgets of energy, water, nutrients, and other forms of matter reveal differences from place to place, show aspects of 'connectedness,' and "assist in identifying a hierarchy of problems for research."]

2. Association of American Geographers. Commission on College Geography. Geography in Undergraduate Liberal Education. Publication No. 1, 1965.

3. Idem, New Approaches in Introductory College Geography Courses. Publication No. 4, 1967. 174pp. [These provided the basic guidelines for this course outline.]

4. Budyko, M.I. The Heat Balance of the Earth's Surface. Translated by N. Stepanova. Washington: U.S. Weather Bureau, 1958. 258pp.

5. Budyko, M. I. and Gerasimov, I. P. "The heat and water balance of the earth's surface, the general theory of physical geography and the problem of the transformation of nature." Soviet Geography 2, No. 2: 3-12, 1961.

6. Hare, F. K. "The concept of climate." Geography 51: 99-110, 1966. [Importance of the exchange processes]

7. Idem, "Climatology and the geography student." Canadian Geographer 4, No. 16: 36-38, 1960. ["...the physical interactions between land, sea, air and living cover..."]

8. Landsberg, H. E. "Trends in climatology." Science 128: 749-758, 1958.

9. Idem, "Goals for climatology." Journal of the Washington Academy of Science 52: 85-90, 1962. [Both emphasize the importance of budgets of energy and moisture in differentiating the climates of the world.]

10. Linton, D. L. "The geography of energy." Geography 50: 197-228, 1965. [Parameters in diverse fields of geography can all be expressed in energy units.]

11. Miller, D. H. "The heat and water budget of the earth's surface," Advances in Geophysics 11: 175-302, 1965.

12. Thornthwaite, C. W. "The task ahead." Annals of the Association of American Geographers 51: 345-356, 1961. ["Climates owe their individual characteristics to the nature of the exchange of momentum, heat, and moisture between the earth's surface and the atmosphere."]

13. Tweedie, A. D. "Challenges in climatology." Australian Journal of Science 29: 273-278, 1967. [On the heat and water economy. A presidential address]

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D.H.M.

A SHORT INTRODUCTORY UNIT ON THE BUDGETS OF THE CITY

Objectives:

To begin with a type of surface cover that is familiar to most students;
To point out areal differentiation and areal associations within a city;
To compare a city with rural areas that supply it with clean water and clean air;
To introduce the idea of an accounting budget of water and other substances.

Outline:

A. The water input and output of the city

Water delivered by nature as rain or snow; special means taken to speed its departure

Water brought in artificially; disposal in evapotranspiration, and exported as a vehicle loaded with industrial and organic wastes.

B. Other mass budgets of the urban surface

Substances generated in materials handling or energy conversion

Diffusion of these substances through the urban atmosphere, and resulting concentrations of pollutants.

C. How does a citizen perceive input-output relations in his environment?

What conditions does he think citizens in other cities experience?

His attitude toward cities as polluters of water and air, and as environment.

Commentary:

More intensively than any other part of the surface of the earth, cities are converters of energy and matter. While much of this activity occurs within buildings, its products soon come out onto the earth-air interface: sensible heat, sulfur dioxide, water vapor, photochemical substances, and pollutant-charged water are released and enter the energy and mass balance of the urban region. Although complete budgets are not yet available, data on individual fluxes of energy, water, and other forms of matter can be obtained, and the teacher can indicate how they exist within a more general framework.

Such an introductory unit starts where most students already are. They know something vague about city inputs and outputs, and can see how these pieces of information can be organized through budgeting methods. Most students, furthermore, know that major problems facing the United States revolve around cities: how can we make them work better; how can we make them into better environments for people; can they cease being the major pollutors of the land? The connection of urban energy and mass budgets to these questions is obvious.

INTRODUCTORY UNIT

Cities have not yet attracted the attention of the measurers of inflows, storages, and outflows of energy and matter to the extent that glaciers and corn fields have, and no complete budget can be cited for any urban surface. However, considerable material is at hand to illustrate particular fluxes in the urban budgets, and some illustrates spatial associations of two budgets, e.g., water and sediment yield. Some suggestions for classroom use or problems are given in the following topics:

a. Water supply is both a surplus in the budget of the contributing drainage basin and an input to the city. Figures are known for most cities.

b. The budget of precipitation and runoff at the surface that has been urbanized is changed in several ways. Different amounts of precipitation are now delivered, and means are taken to insulate it from the city's functions. At great expense, storm sewers are built as a second drainage network, and snow is bodily removed. Numbers appropriate to the students' own city easily can be obtained from climatic and water-supply records.

c. Water-borne outputs in other budgets include sediment eroded from land bared for building, and organic and industrial materials carried off into other drainage basins. Milwaukee takes little more water from Lake Michigan than it returns to it, but the outflow of solid matter in the outgoing water is four times that in the inflow. Devices to reduce air pollution may add the pollutants to the washwater, thereby mingling the two mass budgets.

d. Energy-budget studies are fragmentary for cities. Some data are cited in order to account, quantitatively, for metabolism (i.e., energy conversion in industry and space heating), and the effects of the surface in generating the urban heat island.

e. Another energy-conversion process is the evaporation of water applied to lawns and trees—an appreciable amount in some places. (Almost half the water that comes into Adelaide by rain and pipeline leaves the city as vapor.)

f. Sources and diffusion of sulfur have been determined in some cities, as patterns of output from the surface and concentration in the urban atmosphere. Most of the sulfur mass budget derives from energy conversion.

Thus, although the teacher cannot at this stage present a complete budget of energy, sulfur, water, or other substances for a city, he may find it useful to present the individual flows as members of budgets that can be understood intuitively for a familiar surface.

References:

1. Air Over Cities. U.S. Public Health Service, Taft Sanitary Engineering Center, Cincinnati, SEC Technical Report A 62-5 (1962). 290 pp. [See papers on "City air—better or worse," "The thermal climate of cities," and "The dispersion and deposition of air pollutants over cities."]

2. Air Conservation. American Association for the Advancement of Science, Washington, 1965, Publication 80. 335 pp. [Urban problems associated with air pollution, with a case study of the San Francisco Bay region and the role of mass transit.]

3. American Society of Heating, Refrigerating, and Air Conditioning Engineers. ASHRAE Guide and Data Book 1964. Applications. New

York, 1964. [Chapter 16 tells how to estimate energy consumption for space heating—an important part of the urban energy budget.]

4. Borchert, J. R. "The surface water supply of American municipalities." Annals of the Association of American Geographers 44: 15-32, 1954. [Where does surface-water supply urban areas? How large are the contributing basins?]

5. Fitzpatrick, J. V., and Heller, A. N. "A dynamic air resource management program, City of Chicago," Journal of the Air Pollution Control Association 15: 297-301, 1965. [One city studies its own atmosphere and the inputs into it.]

6. Holzworth, G. C. "Mixing depths, wind speeds and air pollution potential for selected locations in the United States." Journal of Applied Meteorology 6: 1039-1044, 1967. [Depth and area of the urban atmosphere affect diffusion in it.]

7. Kawamura, T. "Urban climatology in Japan." In: Japanese Geography 1966—Its Recent Trends. Tokyo: Association of Japanese Geographers, Special Publication No. 1, 1966, 61-65. [Distributions of radiation and wind.]

8. Landsberg, H. E. "Controlled climate (outdoor and indoor)." In: Medical Climatology, S. Licht, editor. New Haven: E. Licht, 1964, 663-701. [Includes material on urban and smaller environments of man. Many references]

9. Landsberg, H. E. "The climate of towns." In: Man's Role in Changing the Face of the Earth, W. L. Thomas, Jr., editor. University of Chicago Press, 1956, 584-606. [Differences between city and country that are due to the peculiar nature of the urban surface and atmosphere.]

10. Leighton, P. A. "Geographical aspects of air pollution." Geographical Review 56: 151-174, 1966. [Budget formulation of the problem of the supply of clean air to cities.]

11. Lowry, W. P. "The climate of cities." Scientific American 217, No. 2: 15-23, 1967. [The heat island and the dust dome, and their causes.]

12. Neiburger, M. "Weather modification and smog." Science 126: 637-645, 1957. [Evaluates, by means of the urban energy budget, some wild proposals to do away with the inversion over Los Angeles. An excellent, entertaining illustration of interaction of mass and energy budgets.]

13. Pooler, F., Jr. "Airflow over a city in terrain of moderate relief." Journal of Applied Meteorology 2: 446-456, 1963. [Inflow of clean air into Louisville.]

14. Sekiguti, T., et al. "The geographical distribution of solar radiation in the Tokyo metropolitan area." Tokyo Journal of Climatology I, No. 1: 35-44, 1965. [Cf. papers on air temperature in same issue.]

15. Tabor, E. C. "Pesticides in urban atmospheres." Journal of the Air Pollution Control Association 15: 415-418, 1965. [Country air is not always clean.]

16. Tweedie, A. D. "Water and the city: prospects and problems." Australian Geographical Studies 5: 1-14, 1967. [Presidential address, on the importation of rural water-budget surpluses to Denver and Newcastle, N.S.W.]

17. Van Burkalow, A. "The geography of New York City's water supply: a study of interactions." Geographical Review 49: 369-386, 1959, (Bobbs-Merrill reprint G-243) [Areas that contribute their surplus to the urban water budget have experienced radical changes in land use. See also: N. Perrin, "New York drowns another valley." Harpers 227: 76-83, Aug. 1963. This article points out that waste in the city distribution system has resulted in needless destruction of settlements in these upland surplus-contributing areas. For deficiencies in upland water-budget determinations, see A. Groopman, "Effects of the northeast water crisis on the New York City water supply system." Journal of the American Water Works Association 60: 37-47, 1968. Conflict between New York and Philadelphia has hinged on the water yield of these same uplands.]

18. Waste Management and Control. National Research Council Committee on Pollution. National Academy of Sciences–National Research Council Publication 1400, 1966. 257 pp. [Outputs from urban budgets via three media–water, air, and land. Case study of the Delaware Valley.]

19. Wolman, A. "The metabolism of cities." Scientific American 213, No. 3: 178-190, Sept. 1965. [The three major problems; water input, water output, and air-contaminant output.]

20. Wolman, M. G., and Schick, A. P. "Effect of construction on fluvial sediment, urban and suburban areas of Maryland." Water Resources Research 3: 451-464, 1967. [Output of water and sediment from exposed construction sites, as an illustration of the interaction of two mass budgets.]

21. Woollum, C. A. "Notes from a study of the microclimatology of the Washington, D. C. area for the winter and spring seasons." Weatherwise 17: 262-271, 1964. [Areal distribution of air temperature and precipitation as affected by the city. It turns out that the "official" observations represent the urban area rather poorly.]

[See also references in Unit II, Sections D, E, and F, on urban atmospheres, in Section IV E on urban snow, item VII E-8 on urban erosion, in Section VII F on flood plains, chiefly urban, and in Section VIII C on national water problems, chiefly urban.]

UNIT I. ATMOSPHERIC MOTION NEAR THE EARTH'S SURFACE

Objectives:

To show one aspect of the interactions between the earth's surface and the atmosphere, and to indicate how some relations can be expressed in terms of energy;

To show how properties of the earth's surface affect atmospheric motion and the stress exerted by that motion on the surface;

To note the basic pattern of wind belts, and their connections with conditions at the surface.

Outline:

A. Basic pattern of circulation of the troposphere

Low-latitude general and secondary circulations

Middle- and high-latitude circulation and motion systems

Case studies of cyclonic storms and effects on the surface.

B. The boundary layer of the atmosphere, and its sheltering influence

Relation to relief and inversions

Local wind systems in the boundary layer

The surface sublayer.

C. Energy of the wind

Energy conversion and dissipation of kinetic energy

Frequency of strong winds

Impact of energy on vegetation and soil at the earth's surface.

Commentary:

The purpose of this unit is to illustrate the impact of atmospheric motion on the earth's surface in different conditions, and to describe the chief types of atmospheric circulation that carry energy and water to and fro among different types of surfaces. In this role, the unit does not essay a general meteorology, which would turn into a separate course. In many schools, such courses are offered for students in the liberal arts. These are not the "weather and climate" courses about which Hare[7] and others have expressed doubt, but rigorous courses built around two derivations – one leading from the First Law of Thermodynamics into considerations of atmospheric stability and vertical motion, the other leading from the Second Law of Newton into wind-pressure relations and horizontal-motion systems of middle and large scales. These derivations can be learned by students with little mathematics or physics, if two to three weeks is given to each. Having taught such courses to liberal-arts students, I feel that the rigorous development of these two lines of thought bring the course closer than any

7. Hare, F. K., "Climatology and the geography student," *Canadian Geographer 4*, 16: 36-38, 1960.

other approach (except a laboratory science) to a genuine learning of scientific process. Whether this approach is close enough is uncertain; on balance, I am at times inclined to agree with Havens[8] that meteorology has little to offer in a liberal arts curriculum that is better than a laboratory science or even certain other field sciences.

In any case, the present course cannot spare six weeks to attain whatever liberal-arts values there might be in these derivations of vertical and horizontal motion in the atmosphere. This is the more true because its focus of interest is not the atmosphere but the earth's surface. Yet it is necessary to take account of momentum exchange as well as the other exchanges at the surface. This can be done if we take motion systems as givens, which are not to be explained here, but accepted as phenomena from which we develop effects at the surface. In the same way, we do not, in Unit III, attempt to explain the generation of radiative energy within the sun but simply accept as a given the arrival of certain amounts of radiative energy at the earth's surface. It is no more necessary that this course be preceded by one on atmospheric motion than it be preceded by one on solar physics; while either would be desirable in providing a deeper understanding of what happens at the earth's surface, neither is truly necessary.

The general circulation provides a global pattern that is to be filled in more completely in Unit VIII. The skeletal framework here is intended to set the stage for discussing large-scale transport of energy and moisture via atmospheric movements, because this information will be needed in Units III and IV.

Secondary motion systems are included both for low latitudes and for the disturbed westerlies. The difference in their characters as well as in their connections with the general circulation form a basic differentiation in the earth's climate.

Attention is given to these motion systems as entities. They are real individuals, more real than the means of wind speed or the "prevailing" direction of wind, and appear in a literature with many case studies. They also are systems with inflow and outflow; the energy budgets of hurricanes, for example, are closely connected with that of the sea surface. Considering storms as entities will be found useful, also, when we come to discuss, in Unit IV, the manner of delivery of water from the atmospheric transport system to the surface of the earth.

In many atmospheric situations, a boundary layer forms, in response to the influences of the energy budget and the roughness of the underlying surface. In turn, this layer provides a marked degree of shelter to the surface and reduces much of the force that would otherwise be expended on vegetation or the works of man. It also traps effluvia from the surface--see Unit II. Local wind systems are for the most part accommodated within this boundary layer.

The part of the boundary layer that touches the earth's surface is of great importance from the viewpoint of this course, because through it is transmitted the impact of the whole fluid atmosphere to the surface. The kinetic energy of moving air provides one example of atmosphere-surface relations, and is of interest because it throws a different light upon a topic of protean form—energy—that infuses every unit in the course.

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8. Havens, J. M. "Has meteorology a place in liberal education?" *Weather 13*: 131-134, 1958.

Wind damage to vegetation, soil, and structures provides an interesting example of atmosphere-surface relations. Its peculiar frequency distribution, with extreme wind speeds occurring but seldom, gives a good opportunity to the teacher wishing to acquaint his students with an introduction to statistics. In few elements is the mean value less indicative of damage-creating potential at the earth's surface.

If the teacher wishes to shorten this unit, he should retain the sections on the motion systems of the low latitudes and the disturbed westerlies. These facts will be needed in later consideration of the synoptic element in climate and the role of energy and water advection in the budgets of climatic regions. He also should provide some information on the boundary layer and its conditions of stability and movement, which are so important in discussing pollution of the lower atmosphere in Unit II. He might be advised that in the context of the whole course, there is little time to devote to the aspects of weather that the students can get just as well in high school or on TV—fronts, for instance. (For the same reason there is little time in Unit IV to go into the fascinating and not irrelevant matter of the unique molecular structure of water.) This unit should not exceed 1-1/2 to 2 weeks and should be concentrated on the themes of wind force on the surface and global patterns of wind direction.

References:

Papers on the general, secondary, and local motion systems of the atmosphere have been selected for the following list chiefly as they explain the facts and effects of atmospheric motion upon the earth's surface and its vegetation and cultural mantle. The global pattern and the secondary motion systems generally associated with its major components are described in references listed in Sections A and B. In Section C, several case studies of damage caused by oceanic storms (including, naturally, Stewart's "Storm") are cited, including the one of March 1962, which changed many of our ideas about storm effects.

References on the atmospheric boundary layer and the local wind systems often found in it are given in Section D. In Section E are references on the part of the boundary layer that touches the surface and through which energy moves to be exerted on the surface. In these lowest tens of meters, many investigations of fluxes of vapor, heat, and momentum have been made in late years. Some of these give experimental data on the direct drag, or expenditure of kinetic energy by the moving atmosphere on the surface.

In Section F are cited a few studies on man's methods of converting the kinetic energy of air motion into directly usable power. Though these methods add only negligibly to the world's energy resources, they may help students see that apparently different forms of energy are basically the same. Dissipation of atmospheric kinetic energy in storms is of greater importance, and several papers are cited on the damage-producing capabilities of high winds, their frequency of occurrence, and their effects on vegetation and soil (Section G). In the selection of source materials, emphasis has been placed on the impact of moving air on the earth's surface. References lead up to this subject through a selection of books and papers on atmospheric processes themselves.

Cross-references at the ends of many of the sections of citations suggest topics that can form bridges to later teaching units on energy, moisture, and mass exchange, as well as to units on spatial syntheses, in which the mobility of the atmosphere plays an important role. Each paper or book is cited in the unit to which it is primarily relevant; cross-referencing then denotes its bridging or correlating function. Since this function is vital in a course attempting to integrate many diverse phenomena, special attention should be given to cross-referenced papers.

A. General

1. Petterssen, S. Introduction to Meteorology, Second Edition. New York: McGraw-Hill, 1958. 327 pp. [Perhaps the best book for the teacher who wants to go beyond the superficial kind of "weather and climate" that leaves the student nowhere. Chapter 9 begins with Newton and, mainly by verbal means that can be mastered by students without much knack for symbolic manipulation, develops the principles of horizontal motion in the atmosphere. Chapters 10 through 15 apply these principles to wind systems of different scales in middle and low latitudes.]

2. Riehl, H. Introduction to the Atmosphere. New York: McGraw-Hill, 1965. 365 pp. [Chapters 6 through 10 are particularly relevant in the present connection. This book gives adequate attention to the low latitudes.]

3. Sutcliffe, R. C. Weather and Climate. New York: Norton. 1966. 206 pp. [A fully up-to-date book by an eminent meteorologist with the English skill in using words to convey insight. Winds and weather systems are discussed in Chapters 8 through 11.]

4. Blumenstock, D. I. The Ocean of Air. Rutgers Univ. Press. 1959. 457 pp. [An excellent melding of meteorology and geography. Chapters 3-5 deal with the winds of the sea, the sea-land borders, and the land.]

5. Hare, F. K. The Restless Atmosphere. New York: Harper and Row, 1963. 192 pp. [Lucid, short account of meteorological processes, especially those involved in motion systems. The second part of the book is the best available survey of synoptic climatology, i.e., motion systems, air streams, and orographic and maritime influences on the weather of different parts of the earth.]

6. Brooks, C. F. Why the Weather? Second Edition. New York: Harcourt, Brace, 1935. [Clear explanations of weather phenomena]

7. Hidy, G. M. The Winds. Origin and Behavior of Atmospheric Motion. Princeton: Van Nostrand, 1967. 174 pp. [A college-level paperback published for the Commission on College Physics. It treats cyclones (concentrated, regular vortices) parallel with turbulent eddies that exert stress on the earth's surface, to bring out analogies between motion at these two scales.]

[General material on atmospheric motion can also be found in item A-7 in Unit III.]

B. The General Circulation and Secondary Systems

1. Hare, F. K. "Energy exchanges and the general circulation." Geography 50: 229-241, 1965. [A view of the general circulation of of the atmosphere as a mechanism converting potential energy into kinetic energy in the low-latitude Hadley cell and polar-front cyclones, and dissipating it in the mid-latitude Ferrel cell as well as by friction near and at the surface of the earth. Examples show the budget of kinetic energy to be in balance.]

2. Tucker, G. B. "The general circulation of the atmosphere." Weather 17: 320-340, 1962. [Review paper developing the balance requirements of the circulation.]

3. Lorenz, E. N. "The circulation of the atmosphere." American Scientist 54: 402-420, 1966. [Changes in ideas about the global and secondary circulations.]

4. Mintz, Y. "The observed zonal circulation of the atmosphere." Bulletin of the American Meteorological Society 35: 208-214, 1954. [Belts of convergence, areas of divergence, extents of easterlies and westerlies shown.]

5. Borchert, J. R. "Regional differences in the world atmospheric circulation." Annals of the Association of American Geographers 43: 14-26, 1953. [On the "factors that generate climatic gradients, regions, and boundaries in the lower air."]

6. Pédelaborde, P. Les Moussons. Paris: Libr. Armand Colin (Coll. No. 325), 1958. 208 pp. [Excellent discussion of true and pseudo-monsoon regimes and their geographic characteristics.]

7. Riehl, H. Tropical Meteorology. New York: McGraw-Hill, 1954. 392 pp. [Comprehensive view of weather systems and climatic patterns of the low latitudes, the less understood half of the atmosphere.]

8. Riehl, H. "General atmospheric circulation of the tropics." Science 135: 13-22, 1962. [Review of the low-latitude wind belts and the transports of water and energy associated with their role in the earth's circulation.]

9. Miller, B. I. "Characteristics of hurricanes." Science 157: 1389-1399, 1967. [The hurricane as a system that extracts energy from the ocean surface, concentrates it into a small space, and converts it into different forms on a tremendous scale.]

10. Sugg, A. L. "Economic aspects of hurricanes." Monthly Weather Review 95: 143-146, 1967. [Costs of reconnaissance of offshore hurricanes and of prospective and evasive measures as well as costs due to imprecision in predicting the point of landfall.]

11. Hare, F. K. "The Westerlies." Geographical Review 50: 345-367, 1960. (Bobbs-Merrill reprint G-82) [Review of our knowledge of

the great circumpolar vortices of the middle and high latitudes, and the complex motion systems under their waves. Cf. VIII F-7.]

12. Lamb, H. H. "The southern Westerlies: a preliminary survey; main characteristics and apparent associations." Quarterly Journal of the Royal Meteorological Society 85: 1-23, 1959. [Parallels and contrasts with the weaker, more variable, but more familiar circumpolar vortex of the Northern Hemisphere.]

13. van Loon, H. "Mid-season average zonal winds at sea level and at 500 mb south of 25 degrees south, and a brief comparison with the Northern Hemisphere." Journal of Applied Meteorology 3: 554-563, 1964. [Oceanic dominance except near Australia]

14. Stark, L. P. "Positions of monthly mean troughs and ridges in the Northern Hemisphere, 1949-1963." Monthly Weather Review 93: 705-720, 1965. [Maps of occurrence of axes of ridges and troughs in the 700-millibar topography of the circumpolar vertex.]

15. Reiter, E. R. Jet Streams. Garden City, N.Y.: Doubleday, 1967. Science Study Series under sponsorship of the American Meteorological Society. 189 pp. [Chapter 7 discusses effects of jet streams on phenomena in the atmosphere near the ground.]

[See also Sec. III E on atmospheric energy, Sec. IV D on moisture circulation, and all items under VIII H for global aspects of surface-atmosphere patterns in general. References in Section IV D deal with middle-latitude moisture advection, and items VIII A-1, 2, and 3 with coastal advection.]

C. Studies of Damage by Oceanic Storms

1. Stewart, G. R. Storm. New York: Random House, 1941. 349 pp. [A classic narrative of a Pacific storm and its effects across coastal, valley, and Sierran California. It is as authentic in its account of human activities, especially in the Sierra, as in its meteorology. Standard supplementary reading in many meteorology courses.]

2. Lynott, R. E. and Cramer, O. P. "Detailed analysis of the 1962 Columbus Day windstorm in Oregon and Washington." Monthly Weather Review 94: 105-117, 1966. [Absence of the usual protective boundary layer near the earth's surface allowed a large part of the kinetic energy of this Pacific storm to be expended on forest land. A year's production was destroyed.]

3. Cooperman, A. I. and Rosendal, H. E. "Mean five-day pressure pattern of the great Atlantic Coast storm, March 1962." Monthly Weather Review 91: 337-344, 1963. [Dramatic in its impact on man's works and his thinking about storms, this event was, nevertheless, not rare meteorologically.]

4. Mather, J. R., Field, R. T. and Yoshioka, G. A. "Storm damage hazard along the East Coast of the United States." Journal of Applied Meteorology 6: 20-30, 1967. [Both hurricanes and mid-latitude

cyclones have contributed to the rising totals of damage to land occupiers who have gone into this region of jeopardy. This and following studies resulted from the March 1962 storm of the preceding citation.]

5. Burton, I., Kates, R. W., Mather, J. R. and Snead, R. E. "The shores of Megalopolis: Coastal occupance and human adjustment to flood hazard." Publications in Climatology 18, No. 3: 435-603, 1965. [Survey of occupance and storm hazard along the coastal recreation area of Megalopolis, from reconnaissance and detailed studies at places of varying terrain and economy.]

6. Burton, I. and Kates, R. W. "The floodplain and the seashore. A comparative analysis of hazard-zone occupance." Geographical Review 54: 366-385, 1964. (Bobbs-Merrill reprint G-31) [Analogous hydrologic and geomorphic characteristics of coastal lands and flood plains, and their cultural environments. "The United States is in danger today of embarking on a large-scale and costly program of coastal defense" that may be no more effective than our programs on flood plains.]

7. Davies, J. L. "A morphogenic approach to world shorelines." Zeitschrift fur Geomorphologie 8, Sonderheft: 127-142, 1964. [Impact of storm-generated waves and swell is employed as a means of classifying coast lines.]

[Surface effects on storm systems, for example, air-sea interactions, are discussed in references III E-10 and 11, and VIII F-7 to 10. General relations of storms are discussed in Sec. IV E and items IV A-6 and 8.]

D. The Boundary Layer and Local Wind Systems

1. Jackson, C. I. "The vertical profile of wind at Lake Hazen, N.W.T." Arctic 18: 21-35, 1965. [Roles of orography and atmospheric stability in preserving the protective boundary layer of the atmosphere and reducing impact of the free atmosphere on the earth's surface.]

2. Hosler, C. R. "Low-level inversion frequency in the contiguous United States." Monthly Weather Review 89: 319-339, 1961. [Occurrence in place and time of the conditions that isolate the local air from the free atmosphere]

3. Holzworth, G. C. "Estimates of mean maximum mixing depths in the contiguous United States." Monthly Weather Review 92: 235-242, 1964. [Maps and annual regimes of this important dimension of the lower atmosphere—the volume available to receive and transport urban debris.]

4. Lettau, H. H., and Davidson, B. Exploring the Atmosphere's First Mile. 2 vols. New York: Pergamon, 1957. [Joint program in field

measurement of the boundary layer, to include all important parameters.]

5. Edinger, J. G. Watching for the Wind. The Seen and Unseen Influences on Local Weather. New York: Doubleday. Anchor Science Study Series S 49, 1967. 148 pp. [Paperback sponsored by the American Meteorological Society, on local wind systems, with special attention to their associations with terrain.]

6. Simpson, J. E. "Sea-breeze fronts in Hampshire." Weather 19: 208-220, 1964. [Isochronal mapping of movement of these fronts; relations with the air they displace, and value for gliding.]

7. Fosberg, M. A. and Schroeder, M. J. "Marine air penetration into central California." Journal of Applied Meteorology 5: 573-589, 1966. [Type of sea-breeze front and following marine layer depends on upper-air topography.]

8. Yoshino, M. "Some local characteristics of the winds as revealed by wind-shaped trees in the Rhone Valley in Switzerland. Erdkunde 18: 28-39, 1964. [Illustrates how instrumental data can be extended by use of indicators in the landscape, in order to make an areal differentiation of a long alpine valley on a basis of strength of the up-valley flow. Cf. ref. III C-15 on same valley.]

[Inversions seem to be common features of the boundary layer, and their importance in air-pollution situations has occasioned much recent study; see items II D-7, 8, 9, and 11. Advection of matter in the boundary layer is discussed in papers cited in Sections VII B and C.]

E. The Surface Sub-Layer

1. Munn, R. E. Descriptive Micrometeorology. New York: Academic Press. Advances in Geophysics, Supplement 1, 1966. 245 pp. [Includes the moisture and energy fluxes, as well as wind above uniform surfaces and mosaics of surfaces.]

2. Sheppard, P. A. "Properties and processes at the earth's surface in relation to the general circulation of the atmosphere." Advances in Geophysics 9: 77-96, 1962. [Concise discussion of the exchanges of momentum, energy, and matter at the surface.]

3. Webb, E. K. "Aerial microclimate." Meteorological Monographs 6, No. 28: 27-58, 1965. [Review of wind-speed profiles and turbulent exchanges near the surface, as well as of their associations with turbulent transport of matter and energy.]

4. Priestley, C. H. B. Turbulent Transfer in the Lower Atmosphere. University of Chicago Press, 1959. 136 pp. [Fluxes of momentum, energy, and matter at the earth's surface.]

5. Lumley, J. L. and Panofsky, H. A. Structure of Atmospheric Turbulence. New York: Interscience, 1964. 239 pp. [Characteristics of the atmosphere near the ground, with attention to scale effects.]

6. Thornthwaite, C. W., Superior, W. J., Mather, J. R., and Hare, F. K. "The measurement of vertical winds and momentum flux." Publications in Climatology 14, No. 1, 1961. [Impact of moving air on the earth's surface and the vertical component of its motion.]

7. Lettau, H. H. "Problems of micrometeorological measurements (on degree of control in out-of-doors experiments)." In: The Collection and Processing of Field Data, E. F. Bradley and O. T. Denmead, eds. New York: Interscience, 1967, pp. 3-40. [Field experiments on surface-atmosphere exchanges, with artificial modification of surface roughness and the input of radiative energy.]

[A few items from an extensive literature on fluxes of energy and moisture in the surface sub-layer are referenced in other units of this outline; for example, Sections III A and E and IV A and B.]

F. Energy Conversion, and Wind Speed and Frequencies

1. Davidson, B., et al. Sites for Wind-Power Installations. World Meteorological Organization, Technical Note 63, 1964. 38 pp. [Includes description of the wind field near the earth's surface and its content of kinetic energy]

2. Golding, E. W. and Thacker, M. S. "The utilization of wind, solar radiation and other local energy resources for the development of a community in an arid or semi-arid area." In: Wind and Solar Energy, Arid Zone Research 7: 119-126, 1956. [An interesting description of joint utilization of several energy sources in a place where fossil fuel is expensive.]

3. Juul, J. "Wind machines." Arid Zone Research 7: 56-75, 1956. [Feasibility of converting kinetic energy of winds off the North Sea into electrical energy.]

4. U. S. Weather Bureau. "Prevailing direction, mean speed (m.p.h.) and fastest mile of wind." Sheet of the National Atlas of the United States, 1964. [Climatic contribution to the Atlas, with tabular and cartographic presentation of summarized data on wind.]

5. Slusser, W. "Wind rose maps of the United States." Weatherwise 18: 260-263, 1965. [Frequency and strength of wind from each direction, shown in a form that among other things suggests that genuine westerly winds do not 'prevail' at the surface.]

6. American Society of Civil Engineers. Task Committee on Wind Forces. "Wind forces on structures." American Society of Civil Engineers Proceedings 126 III: 1124-1198, 1961. [Thorough discussion of the frequency distribution of the wind field near the ground, and

the probabilities of severe winds on coasts and interior areas of the United States, mapped by H. C. S. Thom.]

7. Thom, H. C. S. "Tornado probabilities." Monthly Weather Review 91: 730-736, 1963. [Data on frequency and areas of tornado swaths are combined to determine the hazard faced by rural and urban areas of the Midwest.]

8. Skaggs, R. H. "On the association between tornadoes and 500-mb. indicators of jet streams." Monthly Weather Review 95: 107-110, 1967. [Extends short-period model studies of these storms over a "time period of climatologically significant length."]

G. Impact of Wind on Vegetation and Soil

1. Inoue, E., Mihara, Y. and Tsuboi, Y. "Agrometeorological studies on rice growth in Japan." Agricultural Meteorology 2: 85-107, 1965. [Interpretive review of extensive, sophisticated research on exchanges of energy, moisture, and momentum between the atmosphere and paddy ecosystem, including such problems as the drying caused by plant vibration during typhoons. An excellent survey for agricultural geographers.]

2. Chepil, W. S. and Woodruff, N. P. "The physics of wind erosion and its control." Advances in Agronomy 15: 211-302, 1963. [Influences of soil properties and cover on erosion, and measures to reduce it. Cf. refs. VII E-15 and 16 on control.]

3. Chepil, W. S., Siddoway, F. H., and Armbrust, D. V. "In the Great Plains: Prevailing wind erosion direction." Journal of Soil and Water Conservation 19: 67-70, 1964. [Map with wind roses based on the cube of wind speed, developed as a guide in laying out shelterbelts and field strips.]

4. Ashwell, I. Y. "Glacial control of wind and of soil erosion in Iceland." Annals of the Association of American Geographers 56: 529-540, 1966. [Local wind systems and their joint action with cultural factors to produce severe wind erosion.]

5. Sears, P. B. "Tell-tale dust." American Scientist 52: 1-15, 1964. [Dust, drought, erosion, particularly in the 1930's, and the significance of dust in history]

6. Chepil, W. S. "Transport of soil and snow by wind." Meteorological Monographs 6, No. 28: 123-132, 1965. [Thorough review of detachment and entrainment of soil particles, as well as transport processes. Control by various measures is discussed.]

7. Chepil, W. S. and Woodruff, N. P. "Sedimentary characteristics of dust storms: I. Sorting of wind-eroded soil material." American Journal of Science 255: 12-22, 1957. "II. Visibility and dust concentration." Ibid., 104-114. [Part I describes the impoverishment

of the fine fractions of wind-damaged soil, Part II estimates atmospheric mass transport of soil out of the region.]

[Air motion in relation to the energy, gas, and water budgets of plants is discussed in items V F-5 and 6, and VI B-4. Particular references to wind shelter are VI E-5 to 7, VI G-7, VII B-8 and 9. Windfall (VII B-7) and wind erosion of soil (VI E-9 to 11, and VIII D-1 to 5) suggest the effects of wind impact on the surface of the earth.]

Problems:

Abundant data on wind speeds are published in frequency form by the U. S. Weather Bureau. Values for individual months at several hundred places are published in "Local Climatological Data" (LCD), and summaries over 10-year periods in the "Decennial Census of U.S. Climate: Summary of Hourly Observations" (Climatography of the United States, series 82). For quantities as variable as wind speed, hourly measurements are the most realistic figures, and students can work out answers to many important local problems from wind-speed frequencies.

1. Graph monthly values of wind-speed frequencies greater than 12 m.p.h., or less than 4 m.p.h. (important in pollution questions), to identify changes in wind regime with the season, and consequent changes in one factor in urban air pollution.

2. Graph wind-speed frequencies every two hours through the 24-hour cycle to show diurnal changes—likely to be especially marked in summer.

3. What is the probability of tornado damage to your city (ref. F-7)? Is anyone worried about them? Does the building code take account of them?

4. Compute and graph cubes of wind speeds in each class in a winter month, to assess the energy content of air flow (see Arid Zone Research 7).

5. Make a wind rose of frequencies of speeds from each direction, to determine the relative frequencies of northerly vs. southerly winds in hours' duration, in miles travelled, and in energy content.

6. Calculate the wind-erosion factor for local soil conditions from Chepil's equation (ref. I G-2 or G-6, or VI E-9).

7. From maps in the Climatological Data National Summary (issued monthly), plot regimes at stations in different wind regions of the country in some particular year. For example, choose Honolulu, San Diego, San Francisco, Seattle, Juneau, and Fairbanks for a latitudinal sample.

8. From the several U. S. maps in references D-2 (inversions), D-3 (mixing layer), F-4, F-6 (high winds), have students read off data for your city in the season of greatest air pollution hazard.

UNIT II. EXCHANGES OF MATTER (EXCEPT WATER) AT THE EARTH'S SURFACE

Objectives:

To discuss an immediate urban problem in terms of budget accounting;
To bring out the idea of cycles of different substances, insofar as they pass through exchange processes at the surface;
To show the earth's surface as the ultimate source of substances in the atmosphere;
To note some economic, institutional, and social aspects in the problem of air pollution, and thus the interplay of cultural factors with processes at the earth's surface.

Outline:

A. Global aspects of atmospheric composition.

B. Exchanges between biosphere and atmosphere

A case study of nutrient cycling with an atmospheric link

The cycle of carbon in vegetation, soil, and atmosphere

Biological materials (pollen and spores)

Substances of biological importance (pollutants and biocides).

C. Atmospheric inversions and diffusion processes

Methods of estimating "air supply" and ventilation

Geographical distribution of high potential for pollution.

D. Pollution as an urban problem

The paleotechnic atmosphere–sulfur and smoke

Where has pollution been controlled, what did it cost, who paid?

The neotechnic atmosphere–photochemical smog

Case study of an urban atmosphere

Methods of climatological analysis.

Commentary:

Material in Unit I on the atmospheric boundary layer, height of inversions, and wind speeds in this lowest layer had only secondary interest before urbanization and industrialization speeded up the surface-atmosphere exchange processes. Inversion is now, however, a common word and what we used to consider refreshing lake and sea breezes, two decades ago, now are seen as traps for our own toxic wastes. The concepts of Unit I have thus been given new meaning by reason of the exchange process between surface and atmosphere to be discussed in Unit II.

UNIT II

This unit includes both the exchange processes which have developed the world-wide atmosphere as we now have it, and also the rapid atmospheric changes resulting from localized but massive movements of sulfur, hydrocarbons, nitrogen oxides, lead, and other forms of matter upward from the surface of urban regions.

If the teacher wants to shorten this unit, he should retain a discussion of quality of the environment as a problem of modern cultures. Air pollution lends itself better than water pollution, taken up in Unit VII, to investigating areal distributions, and in many minds might be considered more "environmental" in the sense of a milieu surrounding our urban culture and artifacts.

Much of our current difficulty with atmospheric pollution stems, as is well known, from energy conversions in the power plants of autos and electric-power systems. These are different in intensity but not in kind from the energy conversions continuously going on in the geographic landscape. In Unit III, which follows, these conversions are discussed.

References:

After citations of general sources on the composition of the earth's atmosphere (Section A), this list of references turns to material connections between atmosphere and the underlying surface, in particular the biosphere (Section C). The exchanges of carbon and oxygen between biosphere and atmosphere have far-reaching implications, both in terms of geologic history and in possibilities that man faces at the moment. He may be creating a rise in carbon dioxide in the atmosphere, with uncertain effects on the radiation budget, and some meteorologists fear that in damaging the plant world he might be destroying the source of oxygen. These relations can be expressed in budget terms, which also can be applied to the cycling of other elements (Sections A and B), including those brought by atmospheric transport into a drainage basin, like sodium and chlorine. Nor has radioactive fallout vanished as one of the problems we all face.

Local transport of matter (in this unit excluding water) involves mixing depth, wind speed and diffusion near the surface, i.e., aspects of the boundary layer mentioned in Unit 1 (Section D). Not all the cited papers on air pollution present material on the exchanges in the budget at the earth's surface, since knowledge about the rates of return of many substances to the surface is fragmentary. However, many papers present information on source emissions of some substance, e.g., sulfur dioxide, and concentrations of it in the urban atmosphere (Section E). A case study of Nashville (Section F) illustrates these, as well as local differentiation within the area of the city. Applications of standard climatological techniques of data-handling close the list of references.

A. General and Global Aspects

1. Junge, C. E. Air Chemistry and Radioactivity. New York: Academic Press, 1963. 382 pp. [Useful source on gases and aerosols in the atmosphere, with somewhat less on radioactivity and the role of precipitation in returning matter to the earth's surface.]

2. Eriksson, E. "Vertical transports and depositions of atmospheric constituents." World Meteorological Organization Technical Note 68:

117-122, 1965. [The release of matter from surface to atmosphere is balanced by its return to the surface, but this is not always a simple gravitational process.]

3. Borovskiy, V. M. "Salt exchange between the sea and the land, and long-term dynamics of soil processes." Soviet Soil Science 1961: 237-244.

4. Jennings, J. N. "The salinity problem in arid lands." Geographical Review 46: 423-425, 1956. [The question of local vs atmospheric origin]

5. Brierly, W. B. "Atmosphere sea-salts design criteria areas." Journal of the Environmental Sciences 8, No. 5: 15-23, 1965. [Salt deposition as a factor in design of military equipment; an effort to bring geographic realities into the ivory tower of engineering practice.]

6. Eriksson, E. "The yearly circulation of chloride and sulfur in nature; meteorological, geochemical and pedological implications, II." Tellus 12: 63-109, 1960.

7. Idem, "The yearly circulation of sulfur in nature." Journal of Geophysical Research 68: 4001-4008, 1963. [Input, storage, and output in mass budgets. Issue 13 of JGR Vol. 68, is devoted to low-concentration but important substances in the atmosphere.]

8. Bleeker, W., editor. Meteorological Factors Influencing the Transport and Removal of Radioactive Debris. World Meteorological Organization Technical Note 43, 1961. 171 pp. [Authoritative studies on diffusion of a particular kind of pollutant and its return to earth.]

9. Fowler, E. B., editor. Radioactive Fallout: Soils, Plants, Foods, Man. Amsterdam: Elsevier, 1965. 317 pp. [Eleven papers, including one by W. H. Langham on contamination of the biosphere.]

10. Leighton, P. A. Photochemistry of Air Pollution. New York: Academic Press, 1961. 300 pp. [Includes a concise chapter on aspects of solar radiation relevant to energizing photochemical reactions of airborne matter.]

[Reference is also made to books by Geiger (item III A-5) and Landsberg (III A-7) and to recent studies in biometeorology (V A-1 to 3). Nutrient or salt budgets are discussed in items V E-1 to 3 for animals, and VII E-1 and VIII B-15 and H-13 for regions. Dust concentrations are discussed in Sec. I G, along with mass transport as a geomorphological factor.]

B. A Case Study of Mass Budgets of a Small Area

1. Bormann, F. H. and Likens, G. E. "Nutrient cycling." Science 155: 424-429, 1967. [Deposition of matter from the atmosphere ties in with water movement through the biogeochemical cycle in an ecosystem.]

2. Juang, F. H. T. and Johnson, N. M. "Cycling of chlorine through a forested watershed in New England." Journal of Geophysical Research 72: 5641-5647, 1967.

3. Likens, G. E., Bormann, F. H., Johnson, N. M. and Pierce, R. S. "The calcium, magnesium, potassium, and sodium budgets for a small forested ecosystem." Ecology 48: 772-785, 1967. [These three papers deal with the same drainage basins in New Hampshire, and balance the input of one anion and four cations from precipitation of water and impaction on foliage with the output of these ions in the streams, considering local inputs from weathering of the rock.]

4. Bormann, F. H., Likens, G. E., Fisher, D. W., Pierce, R. S. "Nutrient loss accelerated by clear-cutting of a forest ecosystem." Science 159: 882-884, 1968. [A sequel, with emphasis on nitrogen.]

C. Exchanges Between Biosphere and Atmosphere

1. Hutchinson, G. E. "The biochemistry of the terrestrial atmosphere." In: The Earth as a Planet, G. P. Kuiper, editor, Volume 2 of The Solar System. University of Chicago Press, 1954, 371-433. [Comprehensive account of atmospheric phenomena "directly or indirectly brought about by the living matter at the surface of the earth."]

2. Eriksson, E. and Welander, P. "On a mathematical model of the carbon cycle in nature." Tellus 8: 155-175, 1956. [In the atmosphere-biosphere-ocean system, how does the carbon cycle change when additional carbon is injected from outside, e.g., from combustion of fossil carbon?]

3. Lieth, H. "Role of vegetation in the carbon dioxide content of the atmosphere." Journal of Geophysical Research 68: 3887-3898, 1963. [The productivity concept]

4. Monteith, J. L. "Gas exchange in plant communities." In: Environmental Control of Plant Growth, L. T. Evans, editor, New York: Academic Press, 1963, 95-112. [Exchange of carbon dioxide and water vapor discussed in terms of resistances to flow: internal resistances (physiologic) and external (aerodynamic).]

5. Woodwell, G. M. and Dykeman, W. R. "Respiration of a forest measured by carbon dioxide accumulation during temperature inversions." Science 154: 1031-1034, 1966. [The upward flux in the CO_2 budget of a pine-oak forest indicates respiration, i.e., the difference between gross and net production by the forest. Cf. VI C-4.]

6. Berkner, L. V. and Marshall, L. C. "The history of the growth of oxygen in the earth's atmosphere." In: Origin and Evolution of Atmospheres and Oceans. P. J. Brancazio and A. G. W. Cameron, editors, New York: Wiley, 1964, 102-126. [This paper describes

the complicated interaction between the budget of atmospheric oxygen and lethal inputs in the budget of radiation. The problem is that the rise in oxygen concentration above 0.001 of the present level "can be attributed only to photosynthesis," yet photosynthetic organisms were subject to "lethal sunburn" when oxygen concentration was low.]

[Oxygen may yet come to be regarded as one of the most important yields we derive from present ecosystems. Reference may also be made to a paper by the same authors, "On the origin and rise of oxygen concentration in the earth's atmosphere." Journal of the Atmospheric Sciences 22: 225-261, 1965.]

7. Feldstein, M., Duckworth, S., Wohlers, H. C. and Linsky, B. "The contribution of the open burning of land clearing debris to air pollution." Journal of the Air Pollution Control Association 13: 542-545, 1963. [From this paper one might conclude that man and fire have long played a role in atmospheric composition.]

8. Gregory, P. H. The Microbiology of the Atmosphere. New York: Interscience, 1961. 251 pp. [Atmospheric influences on release of spores and pollen and on their diffusion. A variety of deposition processes operate to link the budget again with the earth's surface.]

9. Dingle, A. N. "Aeroallergens." In: Medical Climatology, S. Licht, editor, New Haven: E. Licht, 1964, 96-130. [Review paper on pollen, spores, and other matter diffused in the atmosphere that cause allergic reactions.]

10. Rich, S. and Waggoner, P. E. "Atmospheric concentration of cladosporium spores." Science 137: 962-965, 1962. [The diurnal cycle in input of spores into the local air.]

11. Heck, W. W., Dunning, J. A. and Hindawi, I. J. "Interactions of environmental factors on the sensitivity of plants to air pollution." Journal of the Air Pollution Control Association 15: 511-515, 1965. [Damage to vegetation depends on past and current conditions of soil moisture, temperature, light intensity and duration, as well as on pollutant concentration.]

12. Middleton, J. T., Emik, L. O., and Taylor, O. C. "Air quality criteria and standards for agriculture." Journal of the Air Pollution Control Association 15: 476-480, 1965. [Singly and in combination, pollutants affect plants in different ways, some of which are poorly understood. As a result, it is difficult to set standards for permissible levels of concentration of sulfur oxides, fluorides, ozone, PAN, or ethylene, even when the gross effects are plain.]

13. Rudd, R. L. Pesticides and the Living Landscape. University of Wisconsin Press, 1964. 321 pp. [Soil pollution as well as water and air pollution. Describes the networks, some of them in the atmosphere, by which biocides are transported in the landscape.]

14. Tabor, E. C. "Pesticides in urban atmospheres." Journal of the Air Pollution Control Association 15: 415-418, 1965. [Local movement of aerosols from rural to urban land-use types]

[Further material on mass exchanges between biosphere and atmosphere will be found in items III B-3, V F-1 and F-9, VI A-18, B-4, C-4, F-1 to 6, and G-2, for plants and plant communities. Gas-exchange processes of animals are noted in items V D-4 and E-4 and 5.]

D. Atmospheric Phases of Mass Budgets

1. Frenkiel, F. N. and Sheppard, P. A., editors. Atmospheric Diffusion and Air Pollution. Advances in Geophysics 6, 1959. [Basic considerations. Papers by Haagen-Smit on air pollution, Dingle et al. on pollen diffusion and deposition, and by Lettau are noteworthy. See also references in Sections I E and VII C.]

2. Huff, F. A. "Radioactive rainout relations on densely gaged sampling networks." Water Resources Research 1: 97-108, 1965. [Measurements of the flux of radioactive debris to the earth's surface display even more variation than do measurements of rainfall. An error of "20-25% is introduced when a single observation is assumed to represent the mean rainout over areas of 10-12 mi^2."]

3. Pack, D. H. "Meteorology of air pollution." Science 146: 1119-1128, 1964. [Illustrated by trajectories over the Los Angeles basin, frequency of inversions and anticyclonic flow over the eastern United States, and sulfur dioxide concentration calculated over Nashville by a diffusion model.]

4. Panofsky, H. A. and Prasad, B. "The effect of meteorological factors on air pollution in a narrow valley." Journal of Applied Meteorology 6: 493-499, 1967. [Johnstown, Penn.]

5. Miller, M. E. and Holzworth, G. C. "An atmospheric diffusion model for metropolitan areas." Journal of the Air Pollution Control Association 17: 46-50, 1967. [Combination of a budget with a transport-diffusion exercise]

6. Neiburger, M. "Diffusion and air pollution." Bulletin of the American Meteorological Society 46: 131-134, 1965. [Difficulties include the irrelevance of much work on diffusion, and the opposition of vested interests in air pollution. A short but serious paper]

7. Lawrence, E. N. "Atmospheric pollution during spells of low-level air temperature inversion." Atmospheric Environment (London) 1: 561-576, 1967. [Sulfur dioxide levels related to height and persistence of inversion]

8. Kauper, E. K. and Hopper, C. J. "Utilization of optimum meteorological conditions for the reduction of Los Angeles automotive pollution." Journal of the Air Pollution Control Association 15:

210-213, 1965. [The daytime increase in wind speed and inversion height increases the lower atmosphere's ability to "digest pollution" such that a delay in the morning rush hour would improve the mean concentration of oxidant over the day by a substantial amount.]

9. Neiburger, M. "Weather modification and smog." Science 126: 637-645, 1957. [This paper is without doubt one of the funniest things ever to appear in Science. In deadpan style it deflates, by simple budget arithmetic, some of the proposals made to move smog out of Los Angeles. Just about everything has been suggested, including getting rid of the inversion, a suggestion with interesting energy-budget aspects.]

10. McLaughlin, J. F., et al. "Atmospheric pollution considerations affecting the ultimate capacity of a thermal-electric power plant site." Journal of the Air Pollution Control Association 17: 470-473, 1967. [A committee report. In some places, it may be necessary "to put a finite limitation on the maximum capacity that can be installed."]

11. Leighton, P. A. "Geographical aspects of air pollution." Geographical Review 56: 151-174, 1966. [Contains a budget formulation of the problem: Emissions per capita (increasing in spite of controls) times the number of people (the most critical factor), divided by the air supply (little increase possible in the local supply, none in the general) gives a factor that must not exceed the value we can accommodate. A good paper in chemical geography. Cf. item A-10.]

E. Pollution as an Urban Problem

1. Landsberg, H. E. "The climate of towns." In: Man's Role in Changing the Face of the Earth. W. L. Thomas, Jr., editor, University of Chicago Press, 1956, 584-606. [Differences in climate between town and country are due to several causes, of which one is the changed composition of the atmosphere, with effects both direct and indirect, such as reducing radiation income and visual range.]

2. Air Over Cities. U.S. Public Health Service, Taft Sanitary Engineering Center, SEC Technical Report A 62-5 [1962]. 290 pp. [Excellent perspective on urban pollution. Special reference may be made to papers by H. E. Landsberg, "City air—better or worse"; M. Neiburger, "The dispersion and deposition of air pollutants over cities"; W. A. Perkins, "Some effects of city structure on the transport of airborne material in urban areas"; and J. M. Mitchell, Jr., "The thermal climate of cities." Neiburger's maps show areal distributions of sources, including gasoline engines.]

3. Air Pollution. Published for the World Health Organization by Columbia University Press, 1961. 442 pp. [The chapters by H. Wexler and S. Katz are particularly relevant.]

4. Meetham, A. R. Atmospheric Pollution, Third Edition, with D. W. Bottom and S. Cayton. New York: Macmillan, 1964. 301 pp. [Largely on the paleotechnic city, emphasizing smoke, soot, and sulfur. Information about the many technologic and legal control devices that are available.]

5. Battan, L. J. The Unclean Sky. A Meteorologist Looks At Air Pollution. Garden City, N.Y.: Doubleday, 1966. Anchor Books, Science Study Series S 46. 141 pp. [A paperback under auspices of the American Meteorological Society. The discussion of sampling size distributions of particulates indicates the sophistication of measurements needed to establish just what the urban climate is. A popular book with liberal-arts students.]

6. Haagen-Smit, A. J. "The control of air pollution." Scientific American 210, No. 1: 25-31, 1964. (Scientific American reprint 618) [On the complicated airborne reactions in photochemical smog, and the irreversibility of what we have already done. Another good reference for students.]

7. Schueneman, J. J. "Air pollution problems and control programs in the United States." Journal of the Air Pollution Control Association 13: 116-125, 1963. [Between 1950 and 1960, 14 million more people became exposed to continuing heavy and moderate levels of pollution—one of the facts from this nationwide survey.]

8. Dixon, J. P. "Public policy issues in air conservation." Journal of the Air Pollution Control Association 14: 149-153, 1964. ["The meteorological geography of air envelopes does not correspond to the political geography of the area."]

9. Air Conservation. American Association for the Advancement of Science, Publication 80, 1965. 335 pp. [Air pollution was investigated as one of the social issues created by technology. Good background reports in this volume deal with meteorology, and with political, legal, engineering, economic, and sociological aspects, with a case study of the San Francisco Bay region. The discussion of each of eleven pollutants stresses the budget approach, especially sources.]

10. Waste Management and Control. National Research Council Committee on Pollution. National Academy of Sciences—National Research Council Publication 1400, 1966. 257 pp. [Pollution regarded as a system involving three media: land, air, and water, and areally localized in correspondence with population distribution. Good appendices on pollution processes in ecosystems, the transport system, and the residue situation. Appendix 8 is a case study of the Delaware Valley.]

11. Stern, A. S., ed. Air Pollution, 2d Edition, in 3 volumes. New York: Academic Press, 1968. Volume I, Air Pollution and Its Effects. 694 pp. [Excellent essays on the nature, dispersal, and effects of

air pollution, including four on meteorology and climatology; exhaustive reviews on biological effects. Volume 2 deals with measurement and survey. Volume 3 deals with sources and their control. A good reference, on an important aspect of urban land use, circulation, planning, and geography.]

F. A Case Study of an Urban Atmosphere

1. Stalker, W. W., Kenline, P. A. and Paulus, H. J. "Nashville sulfur dioxide emission inventory and the relationship of emission to measured sulfur dioxide." Journal of the Air Pollution Control Association 14: 469-474, 1964.

2. Larsen, R. I., Stalker, W. W., and Claydon, C. R. "The radial distribution of sulfur dioxide source strength and concentration in Nashville." Ibid., 11: 529-534, 1961.

3. Stalker, W. W. and Dickerson, R. C. "Sampling station and time requirements for urban air pollution surveys. Part II, Suspended particulate matter and soiling index." Ibid., 12: 111-128, 1962.

4. Smith, W. S., Schueneman, J. J., and Zeidberg, L. D. "Public reaction to air pollution in Nashville, Tennessee." Ibid., 14: 418-423, 1964.

5. Turner, D. B. "Diffusion model for an urban area." Journal of Applied Meteorology 3: 83-91, 1964.

6. Williams, J. D. and Edmisten, N. G. An Air Resource Management Plan for the Nashville Metropolitan Area. Cincinnati: U. S. Public Health Service, Air Pollution Series No. 18, 1965. 154 pp. [Other reports in this series are also good information sources.]

[These papers illustrate data on pollutant concentrations, deposition at the earth's surface, and emission from the surface that may be useful in teaching micro-distributional patterns within cities. The practical problem of how many sampling sites and times are needed to establish a distribution at a given level of accuracy is also discussed. Maps of source emissions in these and other papers form an interesting aspect of urban geography. They also raise the question of the relative roles of land use (industrial polluters) and urban circulation (the gas engine) as sources.]

G. The Climatology of Atmospheric Composition

1. Zimmer, C. E. and Larsen, R. I. "Calculating air quality and its control." Journal of the Air Pollution Control Association 15: 565-572, 1965. [A statistical climatology of atmospheric constituents that fluctuate so rapidly that the averaging time over which they are sampled becomes one determinant of the measure of concentration. Statistical methods work as well for these culturally-produced elements as for the older measures like wind speed and rainfall; most of the distributions are log normal.]

2. Larsen, R. I., Zimmer, C. E., Lynn, D. A., and Blemel, K. G. "Analyzing air pollutant concentration and dosage data." Ibid., 17: 85-93, 1967. [Summaries of observations of seven constituents in six cities over three years.]

3. McCormick, R. A. "Air pollution climatology," In: Air Pollution, 2d Ed., A. S. Stern, ed. New York: Academic Press, 1968, 275-320. [Treats local air quality and large-scale distributions.]

4. Hilst, G. R. "Meteorological management of air pollution." Ibid., 321-347. [Something for city planners to think about]

5. Garnett, A. "Some climatological problems in urban geography with special reference to air pollution." Transactions of the Institute of British Geographers 42: 21-43, 1967. [A presidential address, reporting results of a long, productive study of Sheffield.]

Problems:

Because atmospheric composition did not arouse interest until recently, there are few long periods of measurements available and they are likely to be very local. For some kinds of information, the teacher's best source is his own metropolitan air-pollution district. Comparisons among cities in different parts of the United States can be made with data from the networks of the Public Health Service (Taft Center, Cincinnati): air-quality data from the national air sampling network (mostly bi-weekly measurements, in many cities), and the continuous air monitoring program (CAMP network, in a few.) Local districts usually publish summarized material.

1. Referring to mixing-depth papers in Unit I (refs. D-2 and D-3), how many cubic kilometers of air come over your city in autumn to dilute x tons of sulfur dioxide from your power plants? What dilution is achieved?

2. Obtain a winter's measurements of dustfall (the most common measurement) from your metropolitan air-pollution control organization, and map them. What is the average wind direction at times of light winds? Does the pattern spread out symmetrically around dust-source zones? Are the people living in this part of town especially aware of dust pollution?

3. Hay-fever sufferers among the students might be interested in reading such papers as reference VII C-2 and II C-8 to 10 for a report. Those who are concerned about biocides in the landscape might be interested in papers like VII C-4 and II C-13 and 14.

4. If your local control district has inventoried the emissions of sulfur dioxide or hydrocarbons, does the map show a radial pattern, of the kind often described for population density in cities? (See item F-2, and Meetham, p. 202). How is it related to circulation density?

5. Map distributions of one or two contaminants in the Nashville atmosphere (refs. F-1 to 6, or others not cited from the same investigation),

and compare with topography and intensity of land use as might be deduced from USGS quadrangles.

6. Compare cities in different parts of the country from Public Health Service data. How does your city stack up with those in regions with a greater or smaller anticyclonic component in their climate? (Some CAMP data are worked up in reference G-2, using sulfur dioxide in Philadelphia as an illustration, and in G-1, using nitrogen oxides in Washington. Other data tabulated in these references could be analyzed according to these examples by students having a numerical bent.)

7. Compare Meetham's maps of smoke, ash deposits, etc., with maps of population distribution in England, and account for correspondences and discrepancies.

8. How does the contrast of urban and rural atmospheres in your region compare with the generalized contrasts summarized by Landsberg in references E-1 and E-2?

UNIT III. EXCHANGES OF ENERGY AT THE EARTH'S SURFACE

Objectives:

To bring out the fundamental considerations of energy—its income, exchange, conversions, and outgo—as they pertain to geography generally, and as they are manifested in different landscapes of the earth;

To show how geographic differentation in energy brings about a differentiation in climate, in a region's hydrology, agronomy, forestry, and urban activities, this differentiation appearing at different scales;

To sample some of the interrelations between energy conversions and other processes taking place in the landscape, and to become aware of the characteristics of the landscape that influence energy phenomena.

Outline:

A. General ideas about energy at the earth's surface

B. Energy budgets in ecologic and economic systems

Energetics in biology

The surface as an energy converter

The geography of natural and mechanical energy.

C. The budget of radiative energy at the earth's surface

Solar radiation received by the surface, and role of surface albedo

Exchange of energy by long-wave radiation

Some applications of radiative energy.

D. Energy exchange between surface and substrate

Temperature of the active surface; remote sensing of temperature

Soil-heat flux and soil temperature as factors of climate

Energy storage in soil and water bodies.

E. Turbulent flux of sensible heat from the surface

Regimes of air temperature; frequencies, areal distributions

Air-sea exchanges; effects of the surface on the atmosphere.

F. Energy budgets applied to regions

Commentary:

Few concepts demonstrate the unity of geography as well as energy. In its manifold forms and in the conversions from one form to another it permeates the tangible and intangible landscape, and integrates our subdisciplines of chemical, physical, bio-, cultural, and economic geography.

UNIT III

It is basic to urban geography since cities exist by converting energy—as also do farm lands. As Linton points out, when you look at the subject with no restrictions as to "the kind of geography or the kind of energy," very few aspects of either are left out. The calorie and the watt are a basic dimension that fits many fields, because changes at the surface of the earth all "imply that work has been done and energy expended."

Material discussed in earlier units includes wind energy, in Unit I, and the consequences of urban energy-conversion activities as increased movement of pollutants into the atmosphere, in Unit II. This Unit deals with energy input, storage, conversion, and outgo at parts of the earth's surface that, while modified or managed by man, process energy at a slower rate than a city. Recent investigations in ecology, following general acceptance of the ecosystem concept in the past decade or two, contribute a great deal of information about energy processing by vegetation, either aquatic or terrestrial. Many of these studies extend into the topic of energy processing by the animal population, so that a complete picture of the energetics of a piece of the earth's surface can be drawn. Study of the individual energy fluxes in this unit thus looks ahead to work in Unit VI on ecosystem energetics.

From a geographic standpoint, this ecological material is welcome because it can be used to put a quantitative footing under areal differentiation in the landscape that is visible but formerly unmeasured. We can now think in terms of the geographic distributions of capacities for storing energy, differences in rates of conversion of energy from one form to another, and differences in the form of the output, to see whether there is on-site consumption or the yield is harvested and transported off-site.

This differentiation occurs at all scales from small to global. At small scales it is familiar from measurements of plant and animal habitats, and from micro-climatic ameliorative measures that extend the season or areal range of a crop. At the large scales the basic differentiation of the earth in terms of energy inputs to the surface looks forward to Unit VIII. Years ago, the meteorologist Sir Napier Shaw pointed out that, in spite of neglect of solar radiation, it, along with precipitation, makes up the two ncipal inputs to the "atmospheric heat-engine." These two inputs are equally as important at the earth's surface, and it is time for geographers and meteorologists to devote as much study to radiation, as a process having great explanatory power, as to such secondary conditions as soil temperature or air temperature near the surface. Our school atlases ought to show areal distributions of solar radiation as fundamental facts in the geographic patterning of the earth. Until then, the teacher has to rely on a wall map or develop his own material to put into the student's hands from cited sources.

This unit discusses how radiative energy occurs in short-wave and long-wave forms, and how flows are directed upward as well as downward. The net resultant of all the radiation fluxes is then partitioned between the downward flux by conduction into the substrate and the upward flux by conduction and eddy diffusion into the air. Discussion of the large amounts of energy involved in changing the physical state of water is left to the next unit. Unit III is the foundation for consideration of evapotranspiration in Unit IV.

The soil-heat flux, i.e., the energy flux into and out of the substrate (including water bodies as well as soils), builds up an energy storage that largely accounts for the basic land/ocean distinction in climatology, and also evens out the fluctuations between day and night and summer and winter. Soil temperature and water temperature, representing energy storage, have a further value because they characterize an important aspect of the environment. Soil temperatures in different months, for instance, are factors in the growth and yield of many crops, and agronomists and climatologists are coming to distinguish soil from air temperature in such studies, and to employ the most significant temperature, that of the active surface of the earth.

The upward sensible-heat flux is (along with long-wave radiation from the surface) a principal means by which the atmosphere is heated—a process about which numbers of misconceptions persist in textbooks—"the underworld of science." This flux accounts for regimens of air temperature, a parameter widely measured but not so easily interpreted as to either cause or effect on phenomena near the earth's surface. In addition to its characterizing one feature of the milieu of plants, animals and man, air temperature indicates sources and movements of air streams that transport massive amounts of energy across the earth's surface—advection, important in Unit VIII.

References:

The list begins with citations to papers on the energy budget in general, and on the place of energy in geography, just coming to be recognized. These are followed by references to material on energetics in ecology and energy in economic production and consumption. Cross-references to descriptions of the role of energy in ecologic and economic systems are given at the end of this group of citations.

The central part of the list presents references to three major transfers of energy at the earth's surface: radiation, substrate-heat flux, and sensible-heat flux, leaving until Unit IV the large subject of latent-heat flux. Under radiation are cited papers on short-wave radiation, albedo, and the exchange of long-wave radiation, i.e., the flux emitted by the surface and that emitted quite independently by clouds and atmospheric gases. Section C includes a few papers on utilization of solar energy, which, like wind energy, is now an unimportant source of power but allows students to see the basic equivalence of different manifestations of energy in nature.

Papers on a neglected parameter, temperature of the active surface of the earth, are included with those on substrate-heat flux in Section D, because surface temperature is the forcing function pushing energy into the substrate or pulling it out. However, it also has a much wider significance in biological and atmospheric relationships. Papers on soil temperature and its role in soil formation are cited, and illustrate both local effects in soil genesis and also the basis for major zonations of soil groups.

Movement of energy from the active surface into the atmosphere is the subject of a number of papers, including some with measurements of the amounts of energy and the resulting changes in air temperature. Few papers on the temperature of the air near the surface are cited. References elsewhere are more than sufficient for examining its sometimes over-rated role as an energy index in geography.

The list of references ends with papers giving regional budgets of energy. These illustrate the capabilities of budget-accounting on a large- as well as on a micro-scale. This technique has been widely applied to polar regions, and other papers are cited in Unit VIII. Following the references themselves are cross-references to papers cited in other units of this outline.

A. General

1. Budyko, M. I. The Heat Balance of the Earth's Surface. Translated by N. A. Stepanova. Washington: U.S. Weather Bureau, 1958. 255 pp.
2. Budyko, M. I., Efinova, N. A., Zubenok, L. I., Strokina, L. A. "The heat balance of the surface of the earth." Soviet Geography 3, No. 5: 3-16, May 1962.
3. Budyko, M. I. "Heat balance of the earth's surface." Translation from explanatory text in Fiziko-Gecgraficheskii Atlas Mira, Moscow, 1964. Soviet Geography 6, No. 5-6: 303-311, May-June 1965.
4. Budyko, M. I. and Kondratiev, K. Y. "The heat balance of the earth." In: Research in Geophysics, H. Odishaw, editor, Volume 2. Cambridge, Mass.: Massachusetts Institute of Technology Press, 1964, 529-554. [These selections summarize parts of a twenty-year program of research at the Voeikov Geophysical Observatory on all components of the energy budget. This program has included laboratory and observatory measurements; field expeditions to desert, mountain, swamp, shelterbelt, irrigated, and other special sites; correlations with other atmospheric data; and mapping at national and world-wide scales. It is perhaps the largest single task ever undertaken by geographers, and has added immeasurably to our quantitative understanding of how the earth's surface functions. Some of the heat-budget maps published in a Heat Balance Atlas, edition of 1963, also appear in the Fiziko-Geograficheskii Atlas Mira; the heat balance atlas (which was reviewed by I. Bennett, "Heat balance of the earth," Geographical Review 56: 123-124, 1966) is, unfortunately, not generally available in this country.]

5. Geiger, R. The Climate Near the Ground, 4th Edition. Harvard University Press, 1965. [A basic work on the energy budget at different kinds of surface—water, snow, soil, low vegetation, forest, and dissected terrain. It reports a great number of descriptive investigations into microclimate and analyzes their results in energy-budget terms, and thereby sets them in a broad, explanatory framework. The discipline of microclimatology began with the first edition of this work, in 1927, and has grown as the book itself has.]

6. Brooks, F. A. Physical Microclimatology (revised). Davis, California: University of California, 1960. [Especially good for radiative heat fluxes, from the author's long experience in such agricultural energy-budget problems as citrus frost protection.]

7. Landsberg, H. Physical Climatology, 2nd Edition. DuBois, Pennsylvania: Gary Printing Co., 1958, 446 pp. [An excellent work in systematic climatology, with special attention to thermal characteristics of climate. It gives attention to the scale parameter, and

discusses climatic phenomena from spot areas up to world-wide patterns.]

8. Miller, D. H. "The heat and water balance of the earth's surface." Advances in Geophysics 11: 175-302, 1965. [A critique of the state of energy- and hydrologic-budget research through 1963.]

9. Earth Science Curriculum Project. Investigating the Earth. Boston: Houghton Mifflin, 1967. 594 pp. [Though written at a 7th- or 8th-grade level, this book, in Chapters 6 and 7, presents energy processes with examples and problems that may be helpful to teachers at higher levels.]

10. Sellers, W. D. Physical Climatology. University of Chicago Press, 1965. 272 pp. [Contains data on energy budgets of surface and atmosphere.]

[See also the review paper by Baumgartner (VI A-18) and books by Rose (VI E-1), Slatyer and McIlroy IV A-13, Slatyer (IV A-14), and Gates (V F-2). For large-scale aspects of the heat budget, see items VIII H-14 to 16.]

B. Energy Budgets in Biologic and Economic Systems

1. Linford, J. H. An Introduction to Energetics. London: Butterworths, 1966. 223 pp. [Valuable orientation to concepts of energy flow in biologic systems, especially the chapters on manifestations of energy, heat energy, and radiant energy.]

2. Lindeman, R. L. "The trophic-dynamic aspect of ecology." With addendum by G. E. Hutchinson. Ecology 23: 399-418, 1942. Reprinted in: Readings in Population and Community Ecology, W. E. Hazen, ed., Philadelphia: Saunders, 1964, 206-225. [Applies ideas of productivity at different trophic levels to elucidate the energetics of three ecosystems and of the systems in a succession.]

3. Waggoner, P. E., Moss, D. N., and Hesketh, J. D. "Radiation in the plant environment and photosynthesis." Agronomy Journal 55: 36-39, 1963. [Is plant growth limited more by deficiency of radiant energy or carbon dioxide input?]

4. Billings, W. E. Plants and the Ecosystem. Belmont, California: Wadsworth, 1964. 154 pp. [A paperback that uses the energy budget as one measure of the plant's environment; seasonal variation is given particular emphasis.]

5. Stamp, L. D. "The measurement of land resources." Geographical Review 48: 1-15, 1958. [Proposes a standard nutrition unit, defined as 10^9 (gram-) calories/year, equivalent to per-capita consumption of food, as a means of rating land.]

6. Linton, D. L. "The geography of energy." Geography 50: 197-228, 1965. [A fine presidential address. –"To my academic colleagues

on both the physical and human sides and the biogeographical middle of the subject I would like to express the hope that my method of expressing salient parameters, in fields as far apart as climatology and social geography, in terms of a common set of units—the watt and the calorie—has value for the future of our subject." Every change at the earth's surface means that energy has been expended; this is discussed as solar, terrestrial, and vital (i.e., under purposeful control by man, mapped in terms of consumption per capita and per unit-area).]

7. Warren, H. V. "Some pertinent facts in energy studies." Canadian Geographer 5, No. 1: 16-23, 1961. [Changes in consumption of fossil and other forms of energy, and their money costs.]

8. Harper, R. A. "The geography of world energy consumption." Journal of Geography 65: 302-315, 1966. [Includes human and other sources of energy as well as the conventional sources, summed up by culture realms. Realms of high consumption are not necessarily those where the production-consumption budget is in surplus.]

[Energy pervades ecologic and economic systems. Some examples referenced in the other units of this outline may be relevant here also:

-energy from sun and wind, I F-1 to 3
-energy generation and atmospheric pollution, II D
-space-heating and pollution, items in II F; space-heating and changes in climate, VIII G-1.
-the depletion of soil moisture, IV F-7 to 9 and IV B
-the formation of dew, IV C-1
-heat stress on living organisms, items in V A
-man in the cold and man in the heat, items in V B and V C
-energy budgets of animals, items in V D, and VI B-11 to 14
-energy in the ecosystem concept, items in VI A;
  -and some case studies: A Danish grassland (VI B-1 to 3), and an English barley field (VI B-4); in English agriculture generally (VI E-5 to 7); in American corn fields (VI F) and forests (VI G and VII A-10.]

C. Radiation—Short-wave, Long-wave, and Whole-spectrum

1. Robinson, N., editor. Solar Radiation. New York: Elsevier, 1966. 347 pp.
2. Kondrat'ev, K. Ya. Radiative Heat Exchange in the Atmosphere. (A Revised and Enlarged Edition. Translated by O. Tedder), New York: Pergamon Press, 1965. 411 pp. [Two recent comprehensive texts, the former stressing short-wave radiation and the second long-wave, and both considering the total radiation budget of the earth-atmosphere system. The general reader can find much of value and interest in both books. For information on radiation he may also turn to any non-elementary text in meteorology, the best, perhaps, still being Physical and Dynamical Meteorology, 2nd Edition, by D. Brunt, Cambridge University Press, 1939.]

3. Reifsnyder, W. E. and Lull, H. W. Radiant Energy in Relation to Forests. Washington: U.S. Department of Agriculture, Technical Bulletin 1344, 1965, 111 pp. [Much of this manual, which was written to help foresters and other land managers in matters pertaining to radiation, deals with radiation in general. It should be useful to geographers and other scientists.]

4. Landsberg, H. E. "Solar radiation at the earth's surface," Solar Energy 5: 95-98, 1961. [Map of world distribution, based on the most complete records.]

5. U.S. Weather Bureau. "Mean daily solar radiation, monthly and annual." Sheet in the National Atlas of the United States, 1964. [Shows the official network of stations, and tables and maps based on reports from them.]

6. Daniels, F. Direct Use of the Sun's Energy. Yale University Press, 1964. 374 pp. [Discusses incoming radiation and its absorption for various purposes: to heat buildings, to heat or distill water, to refrigerate, to cook, to be converted into mechanical or electric energy.]

7. Hodges, C. N., Thompson, T. L., Groh, J. E. and Sellers, W. D. "The utilization of solar energy in a multiple-effect desalinization system." Journal of Applied Meteorology 3: 505-512, 1964. [Calculations of energy input and conversion in a water still at Puerto Peñasco, Sonora.]

8. Pruitt, W. O., Lourence, F. and Crawford, T. V. "Radiation and energy balance changes during the eclipse of 20 July 1963." Journal of Applied Meteorology 4: 272-278, 1965. [Effect of a 24% obscuration of the sun on the fluxes of short-wave and whole-spectrum radiation, and on the latent-heat, soil-heat, and sensible-heat fluxes.]

9. Barry, R. G. and Chambers, R. "Albedo variations in southern Hampshire and Dorset." Weather 21: 60-65, 1966. [Measurements at close range and from the air.]

10. Bray, J. R., Sanger, J. E. and Archer, A. L. "The visible albedo of surfaces in central Minnesota." Ecology 47: 524-531, 1966. [Albedo is related to chlorophyll content of vegetation and other factors.]

11. Kung, E. C., Bryson, R. A., and Lenschow, D. H. "Study of a continental surface albedo on the basis of flight measurements and structure of the earth's surface cover over North America." Monthly Weather Review 92: 543-564, 1964. [Measurements from the air over Wisconsin and, less intensively, over much of North America, are related to surface cover types. Generalizing these relations results in maps of albedo in different seasons and for differing extent of snow cover in winter.]

12. Larsson, P. "The distribution of albedo over Arctic surfaces." Geographical Review 53: 572-579, 1963. [Determined from data on vegetation, ice cover, and snow cover.]

13. Conover, J. H. "Cloud and terrestrial albedo determinations from TIROS satellite pictures." Journal of Applied Meteorology 4:378-386, 1965. [Exemplifies recent advances in use of TV pictures from space to determine radiative properties of the earth's surface. The five papers selected above from many that have recently appeared confirm the views of Thornthwaite and a few others ten years ago that albedo is a basic characteristic of the geographic landscape that has been too long neglected. Cf. ref. F-6 and 8 below.]

14. Olson, C. E., Jr. "Accuracy of land-use interpretation from infrared imagery in the 4.5 to 5.5 micron band." Annals of the Association of American Geographers 57: 382-388, 1967. [Illustrates work on remote sensing, in this case of surface temperature, which is found to vary with moisture, fertility, and cultural practices.]

15. Garnett, A. "Insolation, topography and settlement in the Alps." Geographical Review 25: 601-617, 1935. [Classic quantification of an aspect of land form that affects energy input.]

16. Marshall, A. "The house of glass." Landscape 11, No. 2: 18-21, Winter 1961-2. [Discomfort and added operational expenses are imposed on inhabitants of buildings when architects ignore the realities of solar energy.]

[Some wave-lengths of radiation kill, others foster the organisms that make oxygen—see item II C-6. Radiation has similar selective effects on constituents of the atmosphere—see item II A-10. Radiation budgets of leaves of plants are studied in items in V F, and radiation in ecosystems in items VI C-1 to 3. Remote sensing from space vehicles by use of different parts of the radiation spectrum is discussed in a programmatic way in reference VIII H-9.]

D. Temperature of the Active Surface and Heat Flow Downward from It

1. Tanner, C. B. "Plant temperatures." Agronomy Journal 55: 210-211, 1963. [Brief statement about surface temperature as an index to plant-water regime.]

2. Monteith, J. L. and Szeicz, G. "Radiative temperature in the heat balance of natural surfaces." Quarterly Journal of the Royal Meteorological Society 88: 496-507, 1962. [Surface temperatures of crops.]

3. Lenschow, D. H. and Dutton, J. A. "Surface temperature variations measured from an airplane over several surface types." Journal of Applied Meteorology 3: 65-69, 1964. [In Wisconsin. Surface

temperature is as much as nine C deg above air temperature, wi
large areal differentiation.]

4. Shul'gin, A. M. The Temperature Regime of Soils. Jerusalem: Israel Program for Scientific Translations, 1965. Translated by A. Gourevitch. [Heat flow into and out of soil is influenced by such conditions as vegetation and snow cover. It can be managed for agricultural purposes in summer by tillage, mulching, irrigation, and drainage, and in winter by modifying snow distribution.]

5. Nikiforoff, C. C. "Reappraisal of the soil." Science 129: 186-196, 1959. (Bobbs-Merrill reprint G-169) [Examines the soil in several fundamental ways, including those relating to energy. "Pedogenesis consists of transactions in matter and energy between the soil and its surroundings." "Ceaseless excitation of the soil system by vadose (i.e., solar) energy enables it to function throughout geological history." A thought-provoking paper.]

6. Volobuyev, V. R. "Some questions of the energetics of soil formation." Soviet Soil Science 1958: 722-728. [Evaluates energy involved in soil phenomena—rock weathering, migration of salts, biological conversions, movement of water upward—for purposes of comparison of different regions. Cf. Gerasimov, ref. VI D-4.]

7. Landsberg, H. E. and Blanc, M. L. "Interaction of soil and weather." Proceedings of the Soil Science Society of America 22: 491-495, 1958. [Interactions between atmosphere and substrate include energy exchanges and storages that have important effects on both soil and weather. A clear and concise statement.]

8. Carson, J. E. and Moses, H. "The annual and diurnal heat-exchange cycles in upper layers of soil." Journal of Applied Meteorology 2: 397-406, 1963. [Energy storage over the daily and yearly cycle, from detailed measurements of soil temperature and other properties.]

9. Chang, J.-H. "World patterns of monthly soil temperature distributions." Annals of the Association of American Geographers 47: 241-249, 1957. [Results of an extensive compilation of the scattered data on soil temperature, showing some unexpected features.]

10. Hurst, G. W. and Lenz, Y. "Earth temperature changes in winter 1962-63." Weather 19: 124-128, 1964. [A severe winter, with deep freezing of the soil and a long delay in spring warming while the soil thawed.]

11. Peterson, A. E., Burley, M. W., and Caparoon, C. D. "Frost depth survey: a new approach in Wisconsin." Weatherwise 16: 62-65, 1963. [Measurements of depth of freezing made even in the coldest weather—by gravediggers!]

12. Roth, E. S. "Temperature and water content as factors in desert weathering." Journal of Geology 73: 454-468, 1965. [Re-examines the old idea that heat flux into rock is important in weathering, and hence that mechanical weathering is important in deserts.]

13. Hutchinson, G. E. A Treatise on Limnology. Volume 1, Geography, Physics, and Chemistry. New York: Wiley, 1957. 1015 pp. [Perhaps the most comprehensive, erudite, and literate treatment of any subject within the general orbit of geography. Contains a long discussion of energy budgets of lakes, which were one of the substrate types earliest investigated when research into energy storage began.]

14. Gorham, E. "Morphometric control of annual heat budgets in temperate lakes." Limnology and Oceanography 9: 525-529, 1964. [Relation of energy storage to lake depth, area and other characteristics.]

15. Dutton, J. A. and Bryson, R. A. "Heat flux in Lake Mendota." Limnology and Oceanography 7: 80-97, 1962. [A useful case study of energy storage in the substrate, known in this lake from decades of water-temperature records for biological investigations. Makes a nice illustration of energy storage in water bodies as an introduction to land/ocean contrasts.]

16. Koberg, G. E. and Ford, M. E., Jr. "Elimination of thermal stratification in reservoirs and the resulting benefits." U. S. Geological Survey Water-supply Paper 1890-M, 1965. 28 pp. [Artificial mixing of water layers reduces surface temperature in summer.]

17. Wijk, W. R. van. "Soil microclimate, its creation, observation and modification." Meteorological Monographs 6, No. 28: 59-73, 1965. [Also discusses effects of soil climate on plant growth.]

[A brief discussion of heat acceptance by soil or other substrates is to be found in Petterssen's text (item I A-1), pages 93-97. Soil temperature enters in references on soil climate (items in Sec. VI D), and the effects of mulch on it in items VI E-10 and 11. World patterns of soil climate are included in item VIII H-13. See also Wijk, ref. VI A-8.]

E. Heating the Atmosphere

1. Dyer, A. J., Hicks, B. B., and King, K. M. "The fluxatron—a revised approach to the measurement of eddy fluxes in the lower atmosphere." Journal of Applied Meteorology 6: 408-413, 1967. [Measurement of the sensible-heat flux from earth's surface to atmosphere. Many textbooks tell students that the earth heats the atmosphere, but fail to state how few data we actually have on this everyday process. Instruments like the fluxatron may in time fill this curious gap in our knowledge.]

2. Priestley, C. H. B. "The limitation of temperature by evaporation in hot climates." Agricultural Meteorology 3: 241-246, 1966. (There is an upper limit to air temperature over a well-watered vegetation surface.]

3. Williams, Ll. "Occurrence of high temperatures at Yuma Proving Ground, Arizona." Annals of the Association of American Geographers 57: 579-592, 1967. [Data on temperatures of soil, active surface, and air in hot weather.]

4. Miller, D. H. "The influence of open pine forest on daytime temperature in the Sierra Nevada." Geographical Review 46: 209-218, 1956.
5. Idem. "The influence of snow cover on the local climate of Greenland." Journal of Meteorology 13: 112-120, 1956. [In these two papers, energy conversions and storages are worked out quantitatively to explain the regimes of air temperature and other secondary features of the climates of two contrasting snow-covered regions.]

6. Court, A. "Temperature frequencies in the United States." Journal of Meteorology 8: 367-380, 1951. [Second, third, and fourth moments of the frequency distributions of air temperature show the conservative influence of water in the landscape.]

7. Bailey, H. P. "A method of determining the warmth and temperateness of climate." Geografiska Annaler 42: 1-16, 1960.
8. Idem. "Toward a unified concept of the temperate climate." Geographical Review 54: 516-545, 1964. (Bobbs-Merrill reprints G-9)
9. Idem. "The mean annual range and standard deviation as measures of dispersion of temperature around the annual mean." Geografiska Annaler 48 A: 183-194, 1966. [These three papers on regularities in the variations of air temperature give a basis for the "temperate" nature of a climate derived from the dispersion of air temperature from the global mean, 14°C.]

10. Bunker, A. F. "Heat and water-vapor fluxes in air flowing southward over the western North Atlantic Ocean." Journal of Meteorology 17: 52-63, 1960. [Heating of the air is rapid at first, then decreases.]

11. Pyke, C. B. "On the role of air-sea interaction in the development of cyclones." Bulletin of the American Meteorological Society 46: 4-15, 1965. [Short-term action of the North Pacific on storm development is shown by energy-budget calculations that give values of atmospheric heating by the sea. Cf. ref. VIII F-6 to 10.]

12. Namias, J. "Large-scale air-sea interactions over the North Pacific from summer 1962 through the subsequent winter." Journal of Geophysical Research 68: 6171-6186, 1963. [Persistent effects of oceanic anomalies on the atmosphere.]

13. Dickson, R. R. "The climatological relationship between temperatures of successive months in the United States." Journal of Applied

Meteorology 6: 31-38, 1967. [Persistence in air temperature sometimes is "of local origin arising from the anomalous thermal state of the earth's surface," which affects atmospheric heating.]

14. Lettau, H. "A study of the mass, momentum and energy budget of the atmosphere." Archiv für Meteorologie, Geophysik, und Bioklimatologie, Serie A, 7: 133-157, 1954.
15. Davis, P. A. "An analysis of the atmospheric heat budget." Journal of the Atmospheric Sciences 20: 5-22, 1963. [Efforts to define the heat budget of the atmosphere per se (rather than that of the system surface+atmosphere), still significant to those interested in conditions at the underlying surface.]

[Sensible-heat flux from surface into atmosphere is discussed in conjunction with momentum flux in items in Sec. I E. Sensible-heat and latent-heat fluxes are discussed in items IV B-4 to 12. Movement of sensible heat over short distances in the atmosphere is treated in items referenced in the unit on landscape mosaics, VII B-1 to 4, and over longer distances, as between sea and land, in references I D-4 to 6 and VIII A-1 to 5.]

F. Large-Scale Energy Budgets

1. Kayane, I. "Heat budget of the lower atmosphere in the Kanto Plain, with special emphasis on meso-climatology." Tokyo Journal of Climatology 2, No. 2: 32-37, 1965. [A regional energy budget with advective aspects when a sea-breeze sets in.]

2. Frankenberger, E. Contributions to the International Geophysical Year, 1957-58. I. Measurement Results and Computations of the Heat Balance of the Earth's Surface. Translated by A. F. Spano. Washington: U. S. Weather Bureau, 1962. 109 pp.
3. Aizenshtat, B. A. The Heat Balance and Microclimate of Certain Landscapes in a Sandy Desert. Translated by G. S. Mitchell. Washington: U. S. Weather Bureau, 1960, 90 pp. [These two papers are among the excellent translations published by the Office of Climatology in the Weather Bureau, many of which deal with energy budgets. The study by Frankenberger is a thorough examination of heat fluxes near Hamburg, which he extends, by use of land-utilization data, to the whole state of Holstein. The monograph by Aizenshtat describes energy budgets of bare sand, scrub vegetation, and irrigated cotton near Bukhara, and the resulting differences in microclimate. Both contain material suitable for classroom examples, some of which is summarized in reference III A-8.]

4. Leighly, J. "The extremes of the annual temperature march with particular reference to California." University of California Publications in Geography 6 (6): 191-234, 1938.
5. Idem. "Effects of the Great Lakes on the annual march of air temperature in their vicinity." Papers of the Michigan Academy of Science, Arts, and Letters 27: 377-414, 1942. [Two monographs

presenting qualitative but thorough discussions of the energy budgets of land and water surfaces, and quantitative treatment of their differential effects on the annual cycle of air temperature.]

6. McFadden, J. D. and Ragotzkie, R. A. "Climatological significance of albedo in central Canada." Journal of Geophysical Research 72: 1135-1143, 1967. [Effect on snow cover on regional albedo depends on the area of lakes in the landscape. Energy budgets for 1 and 21 June, before and after disappearance of the snow, indicate the change in disposable energy at the earth's surface and in heating of the overlying atmosphere.]

7. Wyrtki, K. "The average annual heat balance of the North Pacific Ocean and its relation to ocean circulation." Journal of Geophysical Research 70: 4547-4559, 1965. [Energy-budget calculations show an overall heat gain of about 3 x 10^{14} calories/second for the ocean north of 20° S. Latitude, with greatest rate of gain on the east side. The result is seen in an inflow of cold water and outflow of warm in the water budget of the whole ocean.]

8. Donn, W. L. and Shaw, D. M. "The heat budgets of an ice-free and an ice-covered Arctic Ocean." Journal of Geophysical Research 71: 1087-1093, 1966. [Changes in ocean temperature following a possible change in albedo from 0.6 to 0.1. Cf. ref. VIII E-5 to 7.]

9. Jackson, C. I. "Some climatological grumbles." Weather 18: 278-282 and 290-293, 1963. [Beliefs about reasons for coldness of the Arctic, the temperature of biological zero, and the influence of the Gulf Stream on Europe do not hold up when examined from a standpoint of the energy budget.]

[Energy economies of regions also figure in references cited in other units of this outline. Urban regions are heat islands (II E-1 and 2) but often, like other regions, under widespread inversions as well; laughable proposals for destroying the inversion over Los Angeles are analyzed by budget principles by Neiburger in item II D-9. Energy budgets of areally-significant kinds of surface cover that heat the atmosphere have been worked out for forest (for example, VII A-1 to 2); not cited here but worthy of attention are studies from the Institute of Geography in Moscow by Rauner, Dzerdzeevskii, and others, that have come out in various issues of Akademiia Nauk SSSR, Izvestiia, Seriia Geograficheskaia, over the past ten years. Energy-water relations of a forested region of northwestern Russia are described in item VIII D-6.

Energy budgets of snow surfaces are found in references VI B-5 to 10 and VIII E-1 to 7, and for regional landscapes in which snow cover alternates with other types of surface in VII B-3, with hydrologic aspects in VII D-6 to 8. Much recent interest in interactions between oceans and atmosphere revolves around energy storage and the rapidity of transfer of energy from one medium to the other, as shown in items VIII F-1 to 11. Item VIII A-8 presents an energy budget of the Bolivian altiplano and its atmosphere.

UNIT III

For desert surfaces, see items in Section V E. For agricultural regions, where energy and water budgets intermingle in an economically important manner, further reference may be made to items VIII B-1 and 2 (New Zealand) and VIII D-1 to 5 (the Ukraine). Export of energy from a region is presented in item VIII B-24. Energy aspects and implications of possible changes in climate, either natural (VIII G-1, H-4 and 5) or artificial (VIII G-10 and 11), provide a means for evaluating this uncertain feature. Global energy flows and budgets are referred to in items VIII H-2 and 3 and H-14 and 15.]

Problems:

1. Students can gain a general orientation in the equivalence of energy of different forms by converting the figures of Linton (B-6) or Harper (B-8) on the consumption in such energy sinks as North America or Europe into calories per unit area, which then can be compared with incoming solar radiation. A similar problem may be assigned for your metropolitan area: the input of fossil fuel expressed in calories per square centimeter of its area. Stamp's energy rating of farm land (B-5) can be applied to rate land in your region and this again reduced to calories per square centimeter.

2. Map solar radiation over a section of the United States on some particular day, from the tabulated values in Climatological Data National Summary.

3. From the monthly-mean map in Climatological Data National Summary, measure the areas that get more than 700, 600, 500 ly/day in a summer month. Measure areas getting less than 100, 200, 300 ly/day in a winter month.

4. Calculate daily radiation received at the surface from information on date, latitude and so on, as provided in the nomographs of Robinson's chapter 4 (ref. C-1, p. 148-157).

5. What is the variation of surface albedo through the year in your region, from Kung et al. (sec. C)? How does this compare with the values listed in Robinson (ref. C-1, pp. 198-205)?

6. Here are measurements of incoming solar radiation and albedo in the Sierra Nevada on several days in Spring 1946. Calculate amount of energy absorbed by the snow or rock surface.

	March			April				May		
	29	4	10	15	20	30	4	6	10	20
Surface	fresh snow	aging snow	. . . . .			patchy snow	. .		granite	. . .
Albedo	0.83	.62	.57	.52	.42	.39	.34	.22	.11	.08
Insolation, ly/day	469	525	668	679	729	750	720	714	746	728
Absorbed solar radiation	80									

How much of the change in available (absorbed radiation) energy is due to the advance of the season, and how much to change in surface condition?

7. From the data presented on mean short-wave radiation, answer the questions below:

	J	F	M	A	M	J	J	A	S	O	N	D
Barrow, Alaska	0	38	180	380	513	528	429	255	155	41	0	0
Seattle (Univ.)	67	126	245	364	445	461	496	435	299	170	93	59
Medford, Ore.	116	215	336	482	592	652	698	605	447	279	149	93
Davis, Calif.	174	257	390	528	625	694	682	612	493	347	222	148
Soda Springs, Calif.	223	316	374	551	615	691	760	681	510	357	248	182
Los Angeles (Airport)	248	331	470	515	572	596	641	581	503	373	289	241
Riverside, Calif.	275	367	478	541	623	680	673	618	535	407	319	270
Honolulu	363	422	516	559	617	615	615	612	573	507	426	371
Canton I. (3° S, 172° W)	588	626	634	604	561	549	550	597	640	651	600	572
Boise, Idaho	138	236	342	485	585	636	670	576	460	301	182	124
Salt Lake City	163	256	354	479	570	621	620	551	446	316	204	146
Phoenix	301	409	526	638	724	739	658	613	566	449	344	281
Madison, Wisc.	148	220	313	394	466	514	531	452	348	241	145	115
Lincoln, Nebr.	188	259	350	416	494	544	568	484	396	296	199	159
Fort Worth	250	320	427	488	562	651	613	593	503	403	306	245
Blue Hill, Mass.	153	228	319	389	469	510	502	449	354	266	162	135
Washington	177	247	342	438	513	555	511	457	391	293	202	156
Charleston, S.C.	252	314	388	512	551	564	520	501	404	338	286	225
Miami	349	415	489	540	553	532	532	505	440	384	353	316
San Juan	404	481	580	622	519	536	639	549	531	460	411	411

Data are monthly averages in langleys per day from varying periods of record. Source: Mean Daily Solar Radiation, Monthly and Annual. Sheet of the National Atlas of the United States, 1964.

a. From the above data on annual regimes of short-wave radiation, select three pairs of stations (for example, mountain-and-valley, coast-and-inland, northern and southern, east coast and west coast, a familiar and an unfamiliar town). Plot their annual marches, compare the stations in each pair, verbalizing your comparison in two or three sentences.

b. On a base map of the U.S., plot values of insolation in June and draw isarithms. Same for December.

c. Look up latitudes of all stations, grouping them by 10° zones, and calculate zonal means for March, June, September, and December. Now graph your means to obtain latitudinal profiles in each season. Write a sentence or two about each profile. What accounts for the difference between the profiles in June and December?

d. A press release says that an acre of irrigated pasture in Wisconsin will produce, between the end of May and the middle of September, 800 pounds of fine beef. The cookbook says that an ounce of beef has 80 big Calories. Assuming the Madison data above to represent the solar energy falling on the pasture in question, how much of it reaches our table? Discuss some factors that might account for energy that does not enter the sunshine-to-you chain.

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8. Here are some observations made by R. A. Muller and me at an open site with unobstructed horizon, on a clear day.

Blue Canyon, California. Lat. 39°N, Elev. 5280 ft., 18 July 1963

	1147		1818	
Sun height	70°		10°	
Estimated short-wave radiation outside atmosphere	1.83 calories		0.31 cm^{-2} $minute^{-1}$	
measured at ground	1.47	0.07	0.20	0.03
	direct	diffuse	direct	diffuse
upward reflection	0.20	0.01	0.066	0.004
Net short-wave	1.27	0.06	0.13	0.03
**				
Long-wave radiation incoming outside atmosphere	0		0	
incoming at ground	0.51		0.47	
emitted by ground	0.82		0.60	
temp of surface	52 °C		22°C	
net long-wave	-0.31		-0.13	
**				

In the following set of boxes, these values have been entered for the noon (1147) measurement. Fill out the entries in the other box.

	1147				1818			
	Short		Long	Whole	Short		Long	Whole
Downward	1.47	0.07	0.51	2.05				
Upward	-0.20	-0.01	-0.82	-1.03				
Net	1.27	0.06	-0.31	+1.02				

9. Radiation-budget diagrams make good problems when several cells are left blank for the student to calculate and fill in, as a preparation for discussing the differences among the various fluxes shown by the

diagram. For example, the following diagrams can be made from Fleischer's measurements at Hamburg for the year 1954 and the day 5 May 1954:

	s.w.	l.w.	w-s
↓	213	659	872
↑	-39	-737	-776
net	174	-78	96

Mean 1954

s.w.	l.w.	w-s
674	-	1333
-129	-	-947
-	-	-

5 May 1954

Data from Fleischer, quoted in Advances in Geophysics, 11: 193 and 196 (ref. A-8). In langleys/day

The diagram for the year is complete, and shows net absorption of +174 ly/day of short-wave (s.w.) radiation, net loss of -78 ly/day in long-wave (l.w.) radiation, and a net whole-spectrum (w.s.) surplus of +96 ly/day. The diagram for 5 May 1954 is entered with the four fluxes actually measured; the others should be gotten by arithmetic. They can then be compared with yearly average shown in the first diagram.

Similar problems with budget diagrams can be worked out from any set of measurements. Those I have summarized in diagram form in Advances in Geophysics, Volume 11, may be useful to the teacher: desert and mountain surfaces, p. 238; mulched soil, p. 250; desert and cotton fields, p. 253 (also in reference F-3); forest, p. 258.

10. Statistical methods can be applied by students to tabulated values of the net surplus (or deficit) of whole-spectrum radiation, just as to rainfall or other data. Following is a set of measurements of whole-spectrum radiation at an observatory near Leningrad, the figures being monthly totals during eight years. They give rise to several questions for students to interpret. They bring out, in particular, the fact that changes occur from year to year in the same month, often to an extent that the mean changes from one month to the next are overshadowed.

    From these data of monthly net surplus or deficit of all the radiation fluxes at the earth's surface, answer the questions that follow the data:

VOEIKOVO: NET WHOLE-SPECTRUM RADIATION — Langleys/month

	J	F	M	A	M	J	J	A	S	O	N	D
1952	-200	-200	100	4000	6800	7200	6900	4600	1800	100	-400	-600
1953	-500	-700	500	4400	6200	7100	6400	3700	1900	200	-500	-400
1954	-400	-700	700	3700	5700	6300	6600	5600	2100	-100	-900	-500
1955	-800	-400	-600	1600	5000	7300	8100	5700	1800	200	-600	-500
1956	-500	-400	200	2500	8300	9400	7000	4700	2700	100	-300	-400
1957	-600	-500	-500	4000	7600	8700	8500	4700	2200	300	-900	-700
1958	-800	0	-200	3800	6200	8200	7600	4900	2400	400	-400	-1000
1959	-500	-700	400	4200	7500	8600	8300	6100	2300	300	-600	-900

Source: E. P. Barashkova, et al., Radiatsionnyi Rezhim Territorii SSSR, Leningrad: Gidrometeoizdat, 1961, pages 452-453. Measurements were made before 1955 over a bare surface, after 1955 over grass; the plot was covered with snow during winter. Measurements accompanied observations of direct and diffuse downward short-wave radiation and upward short-wave, published in the same source. Voeikovo is 30 km east of Leningrad and is named for a geographer, A. I. Voeikov (1842-1916).

a. Which month during this eight-year period had the largest single and largest mean surplus of radiant energy? Which month had the largest radiation deficit?

b. Take the measurements in September. What is its eight-year mean? How much does radiation vary from year to year, as shown by the standard deviation?

c. How does radiation in September compare to that in August? Compare not only the means but also the range of values one standard deviation above and below the mean. Also compare in specific years.

d. In what months have radiation deficits occurred? In comparing the months that have a mean deficit, do you feel that there are significant differences among them? (Discuss this problem either statistically or verbally.)

e. Using graphical, statistical, or verbal media, give a short description of the annual march of net whole-spectrum radiation at Voeikovo. Do not explain, but simply provide the best brief description you can of the data cited.

f. Now, suggest some factors that you would investigate in order to explain the principal features you brought out in your description. Remember that net whole-spectrum radiation is the resultant of two fluxes of downward short-wave and one of downward long-wave radiation, and of upward short-wave and long-wave fluxes, and that these individual energy fluxes do not necessarily vary together.

11. Soil temperature is fairly easily measured, and observations at depths of 2, 10, and 40 cm through the cooling season of the fall semester or the warming period of the spring semester can give some insight into heat storage in the substrate.

12. Problems on energy storage in the substrate have greatest significance in geography when they illuminate the land-vs-sea problem in climate. Lake temperatures serve well for the ocean, since the disturbing effect of heat advection from low latitudes is absent and storage effect is seen by itself (references D-13 to 15). Comparisons can be made with measurements of energy storage in the soil (references D-4 or data in Geiger's book, A-5).

13. Sensible-heat flux from surface into atmosphere is shown by data of Frankenberger (Reference F-2), from which students can plot isopleth diagrams, with month as abscissa and hour as ordinate. He also presents air temperature, which can be plotted in the same way.

14. Sensible-heat flux maps are presented by Budyko (A-1) and the Fiziko-geograficheskii Atlas Mira (VIII H-16). Comparison of places picked off these distributions will give students some idea of the range of values of this energy flow.

15. Budyko's book (reference A-1) contains a number of graphs of yearly regime of net surplus of whole-spectrum radiation and sensible-heat flux, from which problems can be assigned. For example, the regimes at Manaos (p. 118) and Saigon (p. 119) can be plotted by students, along with air temperature from some other source, and the differences between the two places explained. In both, there is a nice tie between sensible-heat flux and air-temperature change from month to month.

16. Heating of the atmosphere is shown by vertical profiles of temperatures, such as those presented by Geiger, Aizenshtat (reference F-3) and Williams (E-3). Students can be given this material to plot and see the great temperature differences that occur close to the ground.

17. Frequency distributions of air temperature are published in the Summary of Hourly Observations (Climatography of the U.S., Series 82), and can be graphed in ways that will bring out its variability. Frequencies of daily maximum air temperature can be tallied by students from data in Climatological Data for their state, perhaps for two places, one more under lake or ocean influence than the other. Frequencies at ocean stations make a good comparison with land (S. L. Rosenthal, Journal of Meteorology 16: 573-580, 1959).

18. Bailey's papers on the temperate climate (references E-7 to 9) present graphical methods that can be used by students to determine how temperate their city is.

UNIT IV. EXCHANGES OF WATER AT THE EARTH'S SURFACE

Objectives:

To provide a framework, the budgeting of water income and outgo, that will extend the student's present knowledge about droughts and floods and help him interpret the appeals to emotions by which dams and canals are sometimes promoted;

To suggest how the time variability of water deliveries to the surface presents problems in water utilization, and to evaluate through the budget the buffering role played by substrate storage of soil moisture and ground water;

To depict areal distributions in water deliveries to the surface as a form of climatic differentiation, giving rise to schemes for water conveyance;

To indicate the role of the atmosphere as a medium for transfer of water among regions of the world;

To portray the role of the earth's surface-substrate system in storing and giving out water, to help the student evaluate proposals for land-management changes;

To understand how water integrates many of the processes that shape the land and its mantles of soil, vegetation, and local air.

Outline:

A. General considerations about water and changes in its physical state

Melting of ice and snow, freezing of soil water and lakes

Evaporation and evapotranspiration; latent heat.

B. Evapotranspiration or latent-heat flux

Requirement and sources of energy, place of evapotranspiration in the energy budget of the earth's surface

Regimes through the day and year; areal distributions

Influence of land management and land use.

C. Local cycling of water

D. Transport of moisture in the atmosphere

Inflow-outflow budgets of moisture in a continental atmosphere.

E. Precipitation

Storms as organized patterns of moisture removal from the air
Intense storms; depth, area, and duration
Spacing between storms; storm occurrence through the year

Probability concepts in precipitation delivery to the surface

Influences of topography; large-scale patterns of rainfall

Reception of precipitation by the vegetation cover.

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F. Partition of delivered water at the earth's surface

Infiltration; seasonal changes and influence by vegetation

Percolation to deeper layers; translocation of nutrients

Climatology of soil moisture; accounting methods of Thornthwaite and others

Influence of soil moisture on growth and yield of vegetation.

Commentary:

It is hard to find a daily newspaper that doesn't have two or three items about water—the impending water shortage and our deaths from thirst; grandiose schemes to move water from here to there, magical ways to extract water from the atmosphere, costs of cleaning up the effluent from the paper industry or suburban lakefront cottages, rising expenditures for boats, water for crops, water for ducks. The citizen is bombarded with schemes, many genuine, but some self-serving, some charlatan, some threatening. This unit, therefore, probably has more relevance to the liberal-arts student than any other single unit in the outline. The framework of the water budget ought to provide students with one means of weighing some of the appeals and threats about water, often emotion-laden, that they will face in later years. The facts that the water budget provides a thread unifying other landscape processes and that it displays marked differentiation from place to place, give it additional geographic meaning.

Material in earlier units has a bearing on the water budget. The motion systems of Unit I are the means by which water is transported and then is concentrated and extracted from the atmosphere. The familiar pairing of wind and rain does not misrepresent this association. Processes of water exchange at the surface were foreshadowed by those of other substances discussed in Unit II. The processes of delivery of substances to the surface, like dry fallout or the precipitation of chlorine in rainwater, and the processes of upward diffusion from the surface into the atmosphere, such as sulfur dioxide, parallel the exchanges of water substances at the surface, both as bulk water and as vapor.

Associations of the water budget with the energy budget of Unit III have been mentioned. It takes energy to melt snow and to evaporate water at the surface, and differences in the output of water vapor are often due to differences in available energy. Since one or two reviewers have reported students having difficulty with the concept of latent heat, teachers should be prepared to emphasize the idea that water does not take wing unless energy is poured into it. It makes no difference whether it is in a teakettle on the stove or in the leaves of corn plants. The meshing of the energy and water budgets, which crops up again and again through this course, revolves around the basic heat of vaporization.

Input-output relations have been well established in hydrology since the times of Horton, before the 1930's, and many observational data are available for the teacher. A special association of the water budget with geography lies in man's stake in the predictable working of the budget. For this reason, his role in changing the budget purposely or inadvertently by modifying characteristics of the earth's surface takes on particular importance. These changes may make the budget's working more predictable, as by storing and conveying water, or less predictable, as has occurred in consequence of disruptions of certain ecosystems. These changes are occurring everywhere in the country, and local examples for teaching should not be hard to find.

It has been suggested that the unit be so arranged that evapotranspiration would follow soil moisture, upon which it depends. If this were done, the teacher would begin with water vapor already in the atmosphere and proceed through the sequence of processes that get it down to the earth's surface, into the soil, and out again through ecosystems into the atmosphere. The sequence proposed in the outline does the same things, but by beginning and ending with phenomena at the earth's surface it emphasizes terrestrial processes over atmospheric. It therefore presents a geographic rather than a meteorological frame of reference by virtue of focussing its attention on the earth's surface, rather than above or below the surface.

As already noted, this unit is confined to on-site terrestrial phenomena, and leaves for later units (Unit VII in particular) the processes of overland movement of water and its concentration into drainage networks. The other synthesizing units likewise consider, often in more detail than is possible for any other budget process, the input-storage-output sequence of water. Differences in evapotranspiration are especially marked on the global scale, and give rise to imbalances in atmospheric transport of vapor. Differences in inputs of water to the surface are best discussed on meso- and global scales (except for the difficult problem of sampling precipitation). Water in one aspect or another is a major cause of differentiation of the earth's surface at small and large scales, and water management as a common objective of man's modification of the surface involves many cultural factors in its geography.

References:

The first section of the reference list cites books and papers of general hydrologic interest that have relevance for the water budget. Some have extensive geographic implications, as shown in the annotations. Section B lists references that are specifically on evapotranspiration as an energy-conversion process associated with energy budgets of the preceding unit. They represent only a small sample of the many papers written since 1948, when Thornthwaite, Budyko, and Penman independently published major contributions to the subject. Vapor flow from surface to atmosphere leads into the subject of local cycling of water, and thence to the total vapor content of the atmospheric column and the movement of vapor over long distances (Sections C and D). This subject has been studied quantitatively, and inflow-outflow budgets of the air space over North America, for example, help us understand the complementary budget of the underlying surface.

Section E includes references on the precipitation of water from the vapor flow aloft to the underlying surface, with attention less to the atmospheric phases, which have been found very complicated, than to what is delivered to the surface. The extreme variability in time and space of this basic input to the surface water budget has been the subject of many papers. The selection includes references on regime and areal patterns. (It might be added here that these lists of references do not include data sources or tabulations.)

Partition of incoming water at the surface into overland runoff and infiltration heads the final section of references, those on water in the soil.

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Soil moisture is a fundamental climatic parameter for the plant world. The accounting concept, with infiltration as input and drainage and evapotranspiration as outputs, brings us back around to the first section of this unit, evapotranspiration, which depends on soil-moisture storage and in turn depletes it. There are many cross-references to other units of the outline. Those at the end of the list of references include papers on the water budget as a whole, as worked out for areas of different sizes.

A. General

1. Chow, Ven Te, editor. Handbook of Applied Hydrology. A Compendium of Water-Resources Technology. New York: McGraw-Hill, 1964. [In teaching the water budget from a systematic point of view, Ch. 3 (meteorology), 4-II (quantitative geomorphology), 6 (ecological aspects), 14 (runoff), 17 (sedimentation), and 25-I (floods) should be of special value. Ch 9, by C. S. Gilman, is probably the best discussion of rainfall to be found anywhere. In teaching the point of view of areal synthesis, Ch. 20 (urban areas), 21 (agricultural lands), 23 (lakes), 24 (arid regions), and 25-V (floodplains) should be valuable. Chapters 26 and 28 deal with resource systems and policy.]

2. Thornthwaite, C. W. and Mather, J. R. "The water balance." Publications in Climatology 8, No. 1: 1-104, 1955. [Authoritative statement on the bases of determining the budget of water at the earth's surface.]

3. Vallentine, H. R. Water in the Service of Man. Penguin Books, A 852, 1967. 224 pp. [A set of essays on water, its unique properties, and the ways of conserving, distributing, and disposing of it, with references to both historical and current technology. A literate effort to humanize engineers.]

4. Linsley, R. K., Kohler, M. A., and Paulhus, J. L. H. Hydrology for Engineers. New York: McGraw-Hill, 1958. 340 pp. [Actually a "Hydrology for Hydrologists," especially in the early chapters. A good text.]

5. Linsley, R. K. and Franzini, J. B. Water-Resources Engineering. New York: McGraw-Hill, 1964. 654 pp. [Sound treatment of hydrologic principles by two leading hydrologists. Sections of the book deal with the works of man and his uses of water.]

6. Bruce, J. P. and Clark, R. H. Introduction to Hydrometeorology. New York: Pergamon, 1966. 319 pp. [This paperback is a useful reference on elementary aspects of hydrometeorology and hydrology, especially for such methods as those for analyzing sparse data. Man's influence is included.]

7. Wisler, C. O. and Brater, E. F. Hydrology, 2nd Edition. New York: Wiley, 1959. 408 pp. [A standard text, with emphasis on stream flow. Although it needs to be supplemented for processes in the water-soil-vegetation system, it is a useful book for students in geography to work through.]

8. Tweedie, A. D. Water and the World. Melbourne: Nelson, 1966. 236 pp. [Water studied in association with the atmosphere, vegetation, soil, land form, and man. No other "single factor contributes more to the landscape variety that becomes the geographer's concern..." A paperback for secondary schools in Australia but appropriate in a beginning college geography course.]

9. Wilgat, T. "Water and its geographic investigation." Czasopismo Geograficzny 32: 183-205, 1961. [With English summary. Good statement of hydrologic geography.]

10. Australian Academy of Science. Water Resources Use and Management. University of Melbourne Press (New York: Cambridge Univ. Press), 1964. 529 pp. [A book full of instructive essays on water fluxes and the water budget in principle, in operation, and in its cultural-geographic aspects. Many case studies.]

11. Colman, E. A. Vegetation and Watershed Management. An Appraisal of Vegetation Management in Relation to Water Supply, Flood Control, and Soil Erosion. Sponsored by the Conservation Foundation. New York: Ronald, 1953. 412 pp. [Systematic treatment of the use of vegetation alone and in conjunction with structures to control movement of water and soil. Many case studies. Pairs off well with books on streamflow, like Wisler and Brater above.]

12. Strahler, A. N. Introduction to Physical Geography. New York: Wiley, 1965. 455 pp. [One of the few textbooks in geography to treat water as a real presence in the landscape. The discussion of soil moisture, vapor flow, ground water, and stream flow, hydrologically sound, forms a credible basis for water as an "agent" in land forming. Includes some of the author's research contributions on drainage networks.]

13. Slatyer, R. O. and McIlroy, I. C. Practical Microclimatology with Special Reference to the Water Factor in Soil-Plant-Atmosphere Relationships. UNESCO, 1961. Printed by Commonwealth Scientific and Industrial Research Organization, Australia.

14. Slayter, R. O. Plant-Water Relationships. New York: Academic Press, 1967. 366 pp. [Excellent treatments of systems at the earth's surface, particularly the evapotranspiration process.]

15. Miller, A. A. The Skin of the Earth. London: Methuen, 1953. [The chapter on water circulation contains useful problems.]

16. Thomas, H. E. "Changes in quantities and qualities of ground and surface water." In: Man's Role in Changing the Face of the Earth, W. L. Thomas, Jr., editor, University of Chicago Press, 1956, 542-563. [The arresting statement that "it is rare indeed to find any evidence of the natural hydrologic conditions prior to man's occupance of a region" makes us regard a regional hydrology as much an artifact as cultivated fields and patterns of settlement.]

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17. Tuan, Yi-Fu. The Hydrologic Cycle and the Wisdom of God. A Theme in Geoteleology. University of Toronto, Department of Geography, Reserach Publication No. 1, 1968. 160 pp. [The circulation of water as a theme that "lent a unity to the multiple facets of physical geography" in the 18th Century, by demonstrating theological design.]

18. "United States National Report, 1963-1967 [to the] 14th General Assembly International Union of Geodesy and Geophysics." Transactions of the American Geophysical Union 48: 323-751, 1967. [This series of reports contains extensive bibliographies of papers of the last three or four years in most areas of the water budget (pages 697-751), as well as regional meteorology (p. 486-504.)]

19. Amorocho, J., and Hart, W. E. "A critique of current methods in hydrologic systems investigation." Transactions of the American Geophysical Union 45: 307-321, 1964. [May be of interest to geographers working with quantitative models, since it discusses parametric and stochastic models of hydrologic systems.]

[General references on hydrologic phenomena and the water budget, in addition to those cited above, are: items I A-4, III A-5 to 10, VI A-18 and E-1, and items in Sections VII-D and E, and VIII C and D.]

[To the investigations and case studies of hydrologic phenomena in Australia in the books by Vallentine, Tweedie, and the Academy of Sciences (refs. A-3, 8, and 10) might be added items III E-2, IV B-8 and VII B-1 and 2 on evapotranspiration (a subject of much attention), IV E-18 on precipitation, IV F-2 on infiltration, and VII D-16 on ground water. It might be noted that Australian geomorphology, a vigorous field of research, makes good use of hydrologic concepts and data. Regional hydrologies are the subjects of references VII E-17 and E-18 on the Australian Alps by Costin, VII D-2 to 4 on the interior by Slatyer and Turner of the CSIRO, and VII F-4 to 7 on the Hunter Valley. Comments on recent water-budget work are included in my notes in the Transactions of the American Geophysical Union 48: 811-816, 1967; Bulletin of the American Meteorological Society 48: 269-270, 1967; and Professional Geographer 19: 201, 1967.]

B. Evapotranspiration

1. Thornthwaite, C. W. "An approach toward a rational classification of climate." Geographical Review 38: 55-94, 1948. [Without getting into the question whether any climatic classification can be "rational," it should be noted that this paper has been used less for classification than for two other features. One of these is a means of keeping books on soil moisture as a primary parameter in climate. The other is an empirical but generally workable formulation for depletion of soil-moisture storage, which drew upon the author's long research on evapotranspiration.]

2. Idem. "Modification of rural microclimates." In: Man's Role in Changing the Face of the Earth. W. L. Thomas, Jr., editor. University

of Chicago Press, 1956, 567-583. [The most important modification is a change in the water budget due to irrigation, with consequent shifts in the soil-moisture accounting system.]

3. Curry, L. "Thornthwaite's potential evapotranspiration term." Canadian Geographer 9: 13-18, 1965. [Explains why the empirical expression for evapotranspiration works.]

4. Sibbons, J. L. H. "A contribution to the study of potential evapotranspiration." Geografiska Annaler 44: 279-292, 1962. [A fundamental study of evapotranspiration in its geographic environment.]

5. Chang, J.-H. "On the study of evapotranspiration and water balance." Erdkunde 19: 141-150, 1965. [Itemizes methods of measuring and estimating evapotranspiration in the water budget.]

6. Penman, H. L. "Natural evaporation from open water, bare soil and grass." Proceedings of the Royal Society, Series A, 193: 120-145, 1948. [A classic formulation of relation of evapotranspiration to energy and aerodynamic factors.]

7. Davies, J. A. "The assessment of evapotranspiration for Nigeria." Geografiska Annaler 48 A: 139-156, 1966. [Illustrates procedures in estimating first, solar radiation input, then net surplus of radiant energy and potential evapotranspiration, and finally deficits and surpluses in the water budget.]

8. McIlroy, I. C., and Angus, D. E. "Grass, water and soil evaporation at Aspendale." Agricultural Meteorology (Amsterdam) 1: 201-224, 1964. [One of the most careful experimental determinations of evapotranspiration yet published, with good radiation data as well. See also items IV A-13 and 14.]

9. Milthorpe, F. L. "The income and loss of water in arid and semiarid zones." Arid Zone Research 15: 9-36, 1960.

10. Deacon, E. L., Priestly, C. H. B., and Swinbank, W. C. "Evaporation and the water balance." Arid Zone Research 10: 9-34, 1958. [Two papers on evapotranspiration in relation to the energy budget. Volumes 10, 11, and 15 of the UNESCO series are especially valuable for evapotranspiration, though most of the two dozen or more volumes contain useful material on the water budget.]

11. Tanner, C. B. "Energy balance approach to evapotranspiration from crops." In: Water and Agriculture, R. D. Hockensmith, editor. Washington: American Association for the Advancement of Science, 1960, 173-195. [Improved method of estimating water requirements.]

12. Conaway, J., and van Bavel, C. H. M. "Evaporation from a wet soil surface calculated from radiometrically determined surface temperatures." Journal of Applied Meteorology 6: 650-655, 1967.

[Use of aerodynamic method with measurements of surface temperature by radiometer.]

13. Harrold, L. L., Brakensiek, D. L., McGuinness, J. L., Amerman, C. R., Dreibelbis, F. R. Influence of Land Use and Treatment on the Hydrology of Small Watersheds at Coshocton, Ohio, 1938-1957. U.S. Department of Agriculture Technical Bulletin 1256, 1962. 194 pp. [Includes data on evapotranspiration and percolation as affected by crop and cultivation practices.]

14. LaMer, V. K., and Healy, T. W. "Evaporation of water: its retardation by monolayers." Science 148: 36-42, 1965. [Principles of retarding evaporation; practical aspects in correct application.]

15. Thornthwaite, C. W., and Hare, F. K. "The loss of water to the air." Meteorological Monographs 6, No. 28: 163-180, 1965. [Aerodynamic and energy aspects of evapotranspiration, systems of approximating it developed by Thornthwaite, Penman, and Budyko, and budgeting of soil moisture.]

[Writings on evapotranspiration are often broad in scope and include other turbulent fluxes in the surface sublayer of the atmosphere (I E and I G-1). In other investigations, the companions of evapotranspiration are the non-turbulent energy fluxes, such as soil-heat flow and radiation.

Evapotranspiration as one of the larger members of the energy budget nearly always figures in general budget studies, e.g., those by Budyko's group (III A-1 to 4). The latent-heat flux is often of major concern in such regional energy budgets as III E-2, III F-2 and 3, and III F-7 and 8 (for oceans). It also enters into the human heat budget (V A-6 and 7, V A-11 to 13, and V C-1 to 4) as evaporative cooling, and similarly into budgets of animals (V E-1 to 7). Transpiration from leaves is important in references of Section V F, and from plant communities in items VI A-6 to 9, 18, 19, B-1 to 4, as well as I G-1 (already cited) and VI E and F, representing cropland, and VII A-1 and 2, representing forest.

Suppression of evaporation by monolayers (VI E-12) changes the energy budget, and distillation of water (III C-7) shows the combined heat-and-water budget in artificial surroundings. Other discussions of evapotranspiration, where it has been studied in conjunction with other water-budget components, are referred to in later Units.]

C. Local Cycling of Water

1. Monteith, J. L. "Dew: facts and fallacies." In: Water Relations of Plants, British Ecological Society Symposium 3. London: Blackwells, 1963, 37-56. [Deflates an often exaggerated phenomenon. The role of dew in the water budget is definitely limited by its role in the energy budget.]

2. Court, A., and Gerston, R. D. "Fog frequency in the United States." Geographical Review 56: 543-550, 1966. [A new map of occurrence of fog, with comments on differences in its pattern in the East and the West.]

[Local cycling of water substance and the humidity of the local air are also discussed in the context of city climates (II E-1 and 2) and human comfort (V A-6 and 7 and A-11 to 13). Changes in the vapor stream coming off a dry surface over a moist one are reported in items VII B-1 and 2, and restrictions by water in various forms on the fluctuations of air temperature are discussed in item *III* E-6.]

D. Water Vapor and Vapor Transport

1. Landsberg, H. E. "Die mittlere Wasserdampfverteilung auf der Erde." Meteorologische Rundschau 17: 102-103, 1964. [Maps of worldwide distribution of humidity.]

2. Reitan, C. H. "Distribution of precipitable water vapor over the continental United States." Bulletin of the American Meteorological Society 44: 79-87, 1960. [Amount of vapor in the entire atmospheric column, in its annual regime and geographic distribution.]

3. Drozdov, O. A., and Grigor'eva, A. S. The Hydrologic Cycle in the Atmosphere. Jerusalem: Israel Program for Scientific Translations, 1965, 282 pp. [Thorough discussion of the budget of atmospheric moisture—inflow from distant and local sources, moisture transport into recipient regions. There are analyses of the recycling of water over Eurasia and of effects of irrigation and roughness of terrain caused by shelterbelts.]

4. Drozdov, O. A. "Moisture circulation and its role in natural processes." Soviet Geography 2, No. 2: 12-24, 1961. [Atmospheric circulation of water in relation to phenomena at the underlying surface.]

5. Crisi, A. P. "Hemispheric water vapor balance during 1958." In: Humidity and Moisture. Measurement and Control in Science and Industry, Vol. 2, A. Wexler, editor. New York: Reinhold, 1965, 502-512. [Maps of atmospheric vapor and the zonal and meridional components of its movement in the Northern Hemisphere.]

6. Sutcliffe, R. G. "Water balance and the general circulation of the atmosphere." Quarterly Journal of the Royal Meteorological Society 82: 385-395, 1956. [The fundamental role water plays in the atmospheric circulation. A presidential address.]

7. Benton, G. S., and Estoque, M. A. "Water-vapor transfer over the North American continent." Journal of Meteorology 11: 462-477, 1954. [A thorough study of inflow and outflow of water in the atmosphere above North America, with a comparison of the budget of atmospheric water with that of water at the earth's surface. Maps depict coastlines over which inflow and outflow are strongest. Discussion of changes through the year reveal the surprising fact that summer, which is our rainiest season, is also the season when outflow is larger than inflow: the continent is then a source region for water vapor.]

8. Leighly, J. "On continentality and glaciation." Geografiska Annaler 31: 133-145, 1949.

9. Barry, R. G. "Meteorological aspects of the glacial history of Labrador-Ungava with special reference to atmospheric vapour transport." Geographical Bulletin 8: 319-340, 1966. [Vapor transport in different types of air flow and circulation, in relation to possible initiation of glaciation (Barry) and its extension westward (Leighly).]

10. Rasmusson, E. M. "Atmospheric water vapor transport and the water balance of North America. Part I, Characteristics of the water vapor flux field." Monthly Weather Review 95: 403-426, 1967. 34 figs. [Takes in both North America and the seas south of it whence comes most of its water supply.]

[Transport of water vapor over long distances is also the subject of items in Sec. VIII A and H. Reference may also be made to items on the wind belts in Sec. I B, and to global-scale papers in Sec. III E.]

E. Precipitation

1. Klein, W. H. "Specification of precipitation from the 700-millibar circulation." Monthly Weather Review 91: 527-536, 1963. [Models showing location of heavy precipitation in relation to a 700-mb trough turn out to be different in different parts of the country.]

2. Thornthwaite, C. W. "The life history of rainstorms." Geographical Review 27: 92-111, 1937. [A look at the patterns of the individual systems that deliver water.]

3. Battan, L. J. Radar Observes the Weather. New York: Anchor Books, Doubleday, 1962. 153 pp. [Sponsored by the American Meterorological Society. Radar does not yet accurately quantify the delivery of water to the earth's surface, but neither do rain gages. Radar at least gives a pictorial idea of the complex distribution of this input.]

4. Weaver, R. L. "California storms as viewed by Sacramento radar." Monthly Weather Review 94: 466-474, 1966.

5. Kuettner, J. P., and Soules, S. D. "Organized convection as seen from space." Bulletin of the American Meteorological Society 47: 364-370, 1966.

6. Barrett, E. C. Viewing Weather from Space. New York: Praeger, 1967. 140 pp. [Two new ways of seeing and mapping motion systems in the atmosphere have revealed unexpected patterns. These in part explain the fact that delivery of water to the underlying surface exhibits time and space distributions that are difficult to conceptualize.]

7. Schloemer, R. W. "An empirical index of seasonal variation of intense precipitation over large areas." Monthly Weather Review 83: 302-313, 1955. [One outcome of a long study of flood-producing and probable maximum storms shows how the capability of the

atmosphere to deliver great amounts of water varies from region to region.]

8. Changnon, S. A., Jr., and Stout, G. E. "Crop-hail intensities in central and northwest United States," Journal of Applied Meteorology 6: 542-548, 1967. [Adjusted for changes in susceptibility of wheat and corn to damage at different stages of growth. Hazard decreases eastward from the Rocky Mountain piedmont.]

9. Goree, P. A., and Yonnkin, R. J. "Synoptic climatology of heavy snowfall over the central and eastern United States," Monthly Weather Review 94: 663-668, 1966.

10. Rooney, J. F., Jr. "The urban snow hazard in the United States. An appraisal of disruption." Geographical Review 57: 538-559, 1967. [Snowfall is an input to the water budget that is hard to forecast, often imperfectly perceived and poorly prepared for by its recipients, and evokes different responses in different cities.]

11. Spreen, W. C. "Effect of topography on precipitation." Transactions of the American Geophysical Union 28: 285-290, 1947. [Correlation methods were used to determine the effects of relief on precipitation measurements, in order to find the total precipitation on rugged drainage basins of western Colorado.]

12. Wilken, G. C. "Snow accumulation in a manzanita brush field in the Sierra Nevada." Water Resources Research 3: 409-422, 1967. [Reception of snowfall in wildland sites depends on physical characteristics of the surface.]

13. Ackermann, W. C. "Application of severe rainstorm data in engineering design." Bulletin of the American Meteorological Society 45: 204-206, 1964. [Kinds of storm information needed in designing structures to manage water.]

14. U. S. Weather Bureau. Rainfall Frequency Atlas of the United States, for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. Washington: U. S. Weather Bureau, Technical Report 40, 1961. 61 pp. [Maps of the frequency and duration of individual rain-bringing systems in different parts of the country.]

15. Weiss, L. L. "Sequences of wet or dry days described by a Markov chain probability model." Monthly Weather Review 92: 169-176, 1964. [Typical of many such applications of statistical models to rainfall occurrence.]

16. Marlatt, W., and Riehl, H. "Precipitation regimes over the upper Colorado River." Journal of Geophysical Research 68: 6447-6458, 1963. [Areal summing of daily rainfall values to determine the kinds of organized atmospheric systems that deliver most of the year's water supply to a river basin.]

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17. Crowe, P. R. "The rainfall regime of the western plains." Geographical Review 26: 463-484, 1936. [Frequency methods used to delimit seasons.]

18. Fitzpatrick, E. A. "Seasonal distribution of rainfall in Australia analysed by Fourier methods." Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie B, 13: 270-286, 1964.

19. Gregory, S. "Regional variations in the trend of annual rainfall over the British Isles." Geographical Journal 122: 346-353, 1956.

20. Wallén, C. C. "Some characteristics of precipitation in Mexico." Geografiska Annaler 37: 51-85, 1955. [These three papers use various characteristics of the precipitation regime to regionalize a country: the annual march, secular changes in the annual total, and indexes of variability, respectively. The one by Wallén gives students a good review of ways to deal with variation.]

21. Trewartha, G. T. The Earth's Problem Climates. University of Wisconsin Press, 1961. 334 pp. [Discusses precipitation regimes in relation to patterns of air flow. Regional descriptions of North America and Europe are especially useful.]

[Measurement and analysis of precipitation are described in the references of Section IV-A, most thoroughly by Gilman in reference IV A-1. Precipitation mechanisms are described, in all their newly discovered complexity and organization, in recent meteorology texts, e.g., items I A-1 and 2. G. R. Stewart's "Storm" gives an excellent account of a disturbance that is a rain in the valley, a snowstorm in the mountains (I C-1). Precipitation as a target for the efforts of weather modifiers is the subject of several recent reports and papers, e.g., VIII G-10 and 11. Variations of precipitation in cities (II E-1 and 2) and in the country (II D-2 and VI B-16) show areal distributions to be complicated. Water-budget studies (see note at end of Unit IV) usually report precipitation data, though often uncritically.]

F. Partition of Delivered Water at the Surface; Soil-Moisture Budget

1. Schumm, S. A., and Lusby, G. C. "Seasonal variation of infiltration capacity and runoff in western Colorado." Journal of Geophysical Research 68: 3655-3666, 1963. [Water is partitioned between infiltration and overland flow differently in summer than in winter.]

2. Turner, A. K. "Infiltration, runoff and soil classifications." Journal of Hydrology (Amsterdam) 1: 129-143, 1963. [Problems in determining the infiltration capacity of the surface.]

3. Marshall, T. J. Relations Between Water and Soil. Farmham Royal, England: Commonwealth Agricultural Bureaux, Technical Communication 50, 1959. [One of an excellent series of manuals. This one is particularly clear on a complicated subject. See also VI D-1.]

4. L'vovich, M. I. "Water balance and soil." Soviet Soil Science 1966: 1019-1029. [Role of the soil in the water budget at the surface, and anthropogenic transformations in the budget.]

5. Dreibelbis, F. R. "Use of the nuclear probe in studies of the soil moisture regimen on lysimeters and small watersheds." In: Humidity and Moisture, Measurement and Control in Science and Industry, A. Wexler, editor, volume 2, New York: Reinhold 1965, 106-115. [Seasonal regime of soil moisture, with examples of the effects of land-use practices.]

6. Grindley, J. "The estimation of soil moisture deficits." Meteorological Magazine 96: 97-108, 1967. [Maps of calculated deficit of soil moisture, indicating capacity available to store water from heavy rains.]

7. Thornthwaite, C. W., and Mather, J. R. "The water budget and its use in irrigation." U. S. Department of Agriculture Yearbook 1955: 346-358. [How soil moisture affects the partition of energy at the earth's surface, and how evapotranspiration can be estimated so as to determine the soil-moisture regime through the growing season. Other papers in this Yearbook give further information on irrigation (e.g., those on pp. 247-285 and 358-405). Others discuss water-soil relations (pp. 120-160), and others drainage (pp. 285-327 and 478-576).]

8. Major, J. "A climate index to vascular plant activity." Ecology 44: 485-498, 1963. [Seasonal changes in the water budget as they affect vegetation. Illustrates how water-budget bookkeeping can be applied. Major uses this method in classifying California vegetation (ref. VI A-19, p. 93-126) and finds "no one-to-one correspondence between climatic and vegetation types."]

9. Zahner, R. and Stage, A. R. "A procedure for calculating daily moisture stress and its utility in regressions of tree growth on weather." Ecology 47: 64-74, 1966. [A running accounting of soil moisture identifies days of stress and provides data for interpreting growth of pine trees.]

10. Shaw, R. H. "Prediction of soil moisture under meadow." Agronomy Journal 56: 320-324, 1964. [With reference to stage of plant development.]

11. Dale, R. F., and Shaw, R. H. "Effect on corn yields of moisture stress and stand at two fertility levels." Agronomy Journal 57: 475-479, 1965.

12. Idem. "The climatology of soil moisture, atmospheric evaporation demand, and resulting moisture stress days for corn at Ames, Iowa." Journal of Applied Meteorology 4: 661-669, 1965. [In these two papers, data from the budget of soil moisture are used in the form of no-stress days. These have a definite effect on yield and can be summarized into a climatology. Over a critical 63-day period in the growth of the corn plant, the long-term average was 40 no-stress days. Other papers on corn are cited in Sec. VI F.]

UNIT IV

13. Palmer. W. C. Meteorological Drought. U. S. Weather Bureau Research Paper 45, 1965. 58 pp. [Another way of using calculated soil-moisture budgets for climatological probabilities. The "near-normal operation of the established economy of an area" is related to generally prevailing conditions of soil moisture, to give expectancies of drought severity appropriate to the region, whether western Kansas or central Iowa. Used to make objective determinations of drought severity in connection with disaster-relief measures.]

14. Curry, L. "Seasonal programming and Bayesian assessment of atmospheric resources." In: Human Dimensions of Weather Modification, W. R. D. Sewell, editor. University of Chicago Department of Geography, Research Papers, No. 105, 1966, 127-138. [Means of analyzing the "seasonal programs of activities affected by the soil moisture balance."]

15. van Hylckama, T. E. A. "The water balance of the earth," Publications in Climatology 9, No. 2: 53-117, 1956. [Calculations of storage of water on the land masses of the earth, as snow cover, soil moisture, and ground water. There is a large variation through the year.]

16. L'vovich, M. I. "The water balance of the land." Soviet Geography 2, No. 4: 14-28, 1961.

17. Idem. "The water balance and its zonal characteristics." Soviet Geography 3, No. 10: 37-50, 1962. [Global aspects of the water budget and its pattern over the world.]

18. Gardner, W. R. "Rainfall, runoff, and return." Meteorological Monographs 6, No. 28: 138-148, 1965. [Clear exposition on movement and retention of water in the soil, including infiltration, leaching, percolation, and drainage.]

[Infiltration is discussed in references IV A-1, A-4 to 7, and A-11. Water in the soil is the subject of items III D-5 and 6 on soil climate, and in Section VI D on soils of ecosystems, and their water-nutrient relations. For effects of mulches on water phases of soil climate, see items VI E-10 and 11. Soils geography (VIII H-13) includes material on water relations.]

[Soil moisture as the dominant parameter in a regional economy is illustrated in Zealand (VI B-1 to 3) and New Zealand (VIII B-1 and 2). Both are exemplary groups of studies for supplementary reading by students or illustrative case studies for the teacher. Soil moisture is important in the Great Plains (VIII B-8 to 12), and some budget material has been worked out (item IV F-13).]

[Water percolating downward from the root zone of the soil is seldom measured, but two estimates can be cited: IV B-13 and VI G-8. Its role in soil genesis and metamorphosis is shown in items VI D-4 to 6. Ground water itself is a favorite subject for budget bookkeeping, a few examples being VIII B-19 and B-31 to 34. Outflow from ground water in drainage basins is important in items VII D-10, 12, 13, and 16. A clear example of ground-water relations with surface water is presented in VIII B-33.]

[Surface runoff and concommitant soil erosion are discussed in VI E-8, and the relation of runoff to vegetation patterns in VII D-1 to 3. Collection of water and water-borne material into a drainage network represent off-site processes to be noted in later units of this outline, along with the flood plains that this combined transport process produces. (Unit VII especially).]

[Complete water budgets usually are integrated with other budgets, such as that of energy, and so will be considered in later units of this outline rather than in this unit. However, some foreshadowing may be of interest. Water budgets of organisms usually are associated with exchanges of other forms of matter or of energy; see references V E-1 to 7, for example. Budgets of plant communities are found in references VI A-6 to 9, and 17; VI B-1 to 3; in Sec. VI E for cultural changes, in VI F for cornfields, and VI G for forest.]

[Implicit in the differentiation of "microenvironments" in which early agriculture began are the conditions of soil moisture, shallow ground water, or available channel flow appropriate to different stages of farming technology (VII A-5 to 7). Water budgets of the vegetation cover of large areas are exemplified for irrigated lands in items VIII B-15 to 21, for cropland regions in items VIII D-1 to 5, and for forest in item VIII D-6. Conflicts between uplands and lowlands over water, ever present, are becoming sharper, as noted in item VII E-23 on the Southwest and many other items in unit VII E, VII F, VIII B, and VIII C.]

[Surfaces of water rather than rock and soil also can be characterized by their water budgets. There are, for instance, those of lakes (VIII B-28), mountain snow zones (VII B-3 and VII D-6 to 8), glacier snow fields (VI B-5 to 7) and ice caps (VIII E-1 to 4), and oceans (VIII E-5 to 7 and VIII F-1 to 3). World water budgets also are cited in Unit VIII (items H-14 to 16).]

Problems:

1. In Thomas's diagram (Fig. 111 in reference A-16), showing sequences of hydrologic processes at the earth's surface, have students indicate the general direction and nature of changes that would result from a certain action by man at each of several nodal or critical points in the sequence.

2. Write a critique of Thornthwaite's potential evapotranspiration concept and calculation method (references B-1 and 2), from commentaries by Curry (B-3), Sibbons (B-4), and Chang (B-5) or others. Use numerical examples.

3. In the paper by Benton and Estoque, measure the lengths of the coastline segments over which inflow of water into the continent is presented, and calculate the intensity of flow across the segment in terms of tons per second and cm of coast. This should be done separately for winter and summer. It is especially significant for the Gulf and Pacific coasts. What is the source of summer rain in the Corn Belt?

4. Students could set up a local precipitation network with plastic gages, and compare the 8 A.M. or storm totals in class. How large will you expect differences within the commuting area to be? See also the lab exercise called "Weather Watch" in the ESCP books (ref. III A-9, pp. 26-27; Investigations 3-1 and 8-3 in the Lab Manual (1965 edition) and Teacher's Guide).

5. Daily rainfall data reported by the Weather Bureau in the monthly issues of the state Climatological Data (CD) can be grouped into wet and dry spells. Are dry and wet the same length? Does either seem to have a preferred length? (Optionally, students with a statistical bent could apply the method described in reference E-15.)

6. Accumulate daily rainfall data from the state CD into storm totals. Map these, draw isohyets and measure the areas enclosed within each isohyet. The result is a depth-area curve (described by Gilman in reference A-1). This kind of analysis of rainstorms as individual entities has been a fruitful approach in American hydrology.

7. Extract snowfall in major storms of five past winters from the records. Discuss these data in connection with references E-9 or E-10.

8. Statistically-oriented students may be interested in applying summation methods of reference E-16, 17, or 20 to the relevant rainfall data, to give an analysis of its complicated areal distribution.

9. Different students could be assigned different methods of calculating daily soil-moisture budgets, all beginning with the same rainfall and other data. Methods set forth in references in Section F may be explored. The method used on Houston data in the ESCP text is also recommended (item III A-9, pp. 216-219). (The ESCP lab manual presents the budget problem for Houston as Investigation 9-2, and sets a problem for Charlotte, Investigation 9-3. See also pages 11-23 of Chapter 9 of the Teacher's Guide.) The method used in reference B-7 also might be applied for a longer period. At what season is your area likely to experience soil-moisture stress? How is this reflected in farming practices?

10. Graph the zonal means of soil moisture and other water storage on the land presented in reference F-15, to show latitudinal differences. Do these reflect differences in precipitation or energy supply?

11. Following is a series of questions about the processes of water output in two forms—water evaporated and transpired, and water percolating downward from the root zone into the ground water. This last flow of water seldom is measured, so this special series of measurements at a Department of Agriculture experiment station in southeastern Ohio have unusual interest.

    The following figures are measurements of rainfall on a brome-grass plot near Coshocton, Ohio, in the Appalachian sedimentary plateaus, and of percolation of water downward from the root zone. They are for the April-August period in the years shown, and are given in cm depth over the plot.[9]

9. Data from F. R. Dreibelbis, *J. Soil Water Cons.* *12*: 85-87.

1	2	3	4	5	6	7	8	9	10
	Precip			Perc.					
1947	88			38					
1948	73			15					
1949	83			15					
1950	88			23					
1951	93			33					
1952	91			23					
1953	63			5					
1954	58			0					
1955	70			5					

a. Calculate to the nearest whole number, and list in Col. 8, the differences between rainfall and percolation each summer. This is water that did not get through the root zone and presumably was transpired or evaporated. (Surface runoff was negligible.)
b. Calculate the means of columns 2, 5, and 8.
c. Using Col. 2 mean, calculate the deviation each summer and list it in Column 3. Square these deviations, and list in Col. 4. Add the squares and show the sum of them here:
d. Do the same operations for the data on percolation, using columns 6 and 7. List the standard deviation here:
e. Do the same operations for the data on evapotranspiration, using columns 9 and 10. Show the standard deviation:
f. When you compare each standard deviation with its respective mean, the ratio is largest for which process?
g. Which of these two processes gets the lion's share of the rainfall – percolation or evapotranspiration?
h. Which of them has first claim on incoming rainwater?
i. In the dry years 1953 and 1954, which of these two processes was hit hardest?
j. In the wettest year, which of them benefitted the most?
k. Why does percolation fluctuate more from year to year than does evapotranspiration?

UNIT V. SYNTHESIZING THE ENERGY AND MASS BUDGETS OF ORGANISMS

Objectives:

To begin the syntheses of energy and mass budgets and to see the interaction between them, as evident in such familiar organisms as a leaf or a man;

To identify man as a part of nature, by demonstrating that budget relations associate him with his environment;

To establish leaf budgets as a step toward examining budgets of plant communities and regional landscapes.

Outline:

A. Budgets in biometeorology

B. Man in the cold and the heat

Insulation and activity level

Radiation load

Comfort and stress indexes

Evaporative cooling and water requirement.

C. Budgets of animals

D. Man and animals in the desert

Energy budget under strong radiative input

Water budget; relation to salt budgets.

E. Budgets of the plant leaf

Gas exchange between leaf and air: oxygen, CO_2, water vapor

Absorption of photochemically active radiation; energy conversion in photosynthesis

Energy input from radiation; leaf temperature

Means of disposing of excess heat

Water requirements and consumption.

Commentary:

It is now possible to see the energy and mass transfers of Units II, III, and IV in their simultaneous functioning at the same places on the earth, and to examine their interactions and joint effects. Organizing the last half of the course outline in the direction of increasing scale of size allows us to begin with familiar objects—plants and animals.

While an animal's skin is not the surface of the earth, the principles of heat, moisture, and gas exchange are similar. Moreover, the several exchanges affect one another similarly. Insects, for example, have the problem of taking enough oxygen in through the same surfaces that let water escape—a serious threat to an organism with a large surface-volume ratio.

Larger animals under heavy heat loading have the problem of avoiding loss of too much water through evaporative cooling.

The budgets of plant leaves will lead into the budgets of pieces of the earth's surface, which over great areas is nothing more or less than foliage. For instance, a critical point in an explanation of a mountain climate was found to be the energy budget of the foliage of its pines. Recent botanical and physiological investigations have stressed leaf energy budgets in relation to the conditions in which the vital process of photosynthesis goes on.

Another reason for considering the exchange processes at plant surfaces or animal skins is that these exchanges link the organisms with the environing world. Environment impresses itself on organisms via the flows of energy, water, and gases. These inputs determine the level of different storages in the organism—its internal temperature, water balance and salt balance, and metabolic state--all controlled by complicated regulatory systems. Because these systems are not completely understood, budgets of organisms are not struck in precise terms; but the principle provides an understanding of the way the environment imposes stress on the organism. This holds true also of the budget of a pollutant substance, like carbon monoxide in the blood of city people.

If a teacher wants to go directly from the preceding systematic units of the course to the combining of energy and mass budgets at the scale of plant communities or ecosystems, he might skip this unit. He should, however, indicate to students that the true impact of environment on individual plants and animals is to be found only in studying their individual budgets of water, other matter, and energy. Or he could take only the material on plant leaves, as an introduction to the budgets of plant communities. Whether or not the budgets of human beings should be considered would depend on the orientation of the course as a whole. The degree to which the teacher wants to tie man in with nature, or to build upon the natural interest of his students on the effects of heat, humidity, urban pollutants and solar radiation on their own efficiency and comfort would be the determining factors in his decision.

The succeeding units in the synthesizing part of the course extend the discussion of interlocking budgets of mass and energy initiated in this unit to successively larger areas. The leaf surfaces of this unit become the plant communities and crop fields of Unit VI, the forested drainage basins of Unit VII, and the regional vegetation cover of Unit VIII. The relative emphasis an instructor puts on phenomena at any scale is a matter of individual interest.

References:

The list of references begins with general works in bioclimatology and biometeorology, a growing field in the United States and Europe. References in Sections B and C deal with man in cold and hot regions, drawing on research carried on as a result of world-wide commitments of troops during and after World War II. The budgets of animals, especially desert animals, are instructive because the studies are unusually complete as to mass and energy flows and the physiological reactions of the organism to stress.

The last group of references and perhaps the best founded quantitatively is comprised of those dealing with the plant leaf. Some of the recent interest is associated with massive research on photosynthesis, some with attempts to understand the water requirements of plants better than can be done by studying whole fields.

Some papers listed in later units of the outline may be found relevant in this unit. Certain papers, of course, could have been listed in either; for example, "Meteorology and the Desert Locust" (ref. VII A-15) contains information both on the animals themselves and on their extensive travels in converging air streams, and is classified according to the latter category. Cross-references identify such papers.

A. General

1. Sargent, F., II, and Tromp, S. W., editors. A Survey of Human Biometeorology. World Meteorological Organization, Technical Note 65, 1964. 113 pp. [Authoritative review of relations of radiation and atmospheric conditions to human physiology.]

2. Tromp, S. W., editor. Medical Biometeorology: Weather, Climate, and the Living Organism. Amsterdam: Elsevier, 1963. 991 pp. [Includes effects of weather phenomena, comfort and stress indexes and many other connections between environment and organisms.]

3. American Meteorological Society. Study Group on Bioclimatology, F. Sargent, II, Chairman. "Biometeorology today and tomorrow." Bulletin of the American Meteorological Society 48: 378-393, 1967. [Critique of the state of the art. Major problems include the following: biological effects of humidity and its variation; benefits of small changes in environment; the question whether man can "create more appropriate atmospheres for living organisms than the atmosphere in which these organisms evolved"; the optimum weather in each phenological period of plants and each stage of life cycles of insects; indexes of environmental stress and strain (which are "most unsatisfactory"); the question how much biological variation is associated with weather; what mechanisms form the links between weather and people—what is "weather sensitivity", and what effect has weather on moods of individuals.]

4. Winslow, C.-E. A., and Herrington, L. P. Temperature and Human Life. Princeton University Press, 1949. 272 pp. [Energy conversion in metabolism, and energy transport from the human body. Insulative value of clothing considering weight and radiating area.]

5. Landsberg, H. "Bioclimatology of housing." In: Meteorological Monographs 2, No. 8: 81-98, 1954. [Microclimates of cities, houses, rooms, and other special environments.]

6. Sibbons, J. L. H "Assessment of thermal stress from energy balance considerations." Journal of Applied Physiology 21: 1207-1217, 1966. [Well-grounded study by a geographer who has worked with evapotranspiration; it leads to a means of expressing the "operation of physical laws in the presence of physiological variables" but doubts that in these circumstances any single index is to be found.]

UNIT V

7. Buettner, K. "Thermal comfort as a criterion for the classification of climates." In: Meteorological Monographs 2, No. 8:99-103, 1954. [As good a criterion as some others in current use.]

8. Edman, M. "Nutrition and climate." In: Medical Climatology, S. Licht, ed. New Haven: E. Licht, 1964, 533-556. [Joint consideration of calories, water, and nitrogen balances.]

9. Livingstone, D. A. "Biological aspects of weather modification." Bulletin of the Ecological Society of America 47: 39-78, 1966. [It is possible that cloud-seeding and other purposeful or inadvertent interferences with the weather may have unexpected and unpleasant consequences, and it seems likely that few meteorclogists have considered biological outcomes. See also references VIII G-10 to 12.]

10. Green, J. S. A. "Holiday meteorology: reflections on weather and outdoor comfort." Weather 22: 128-131, 1967. [Simple equations relating clothing requirements for a given level of exercise to anticipated sunshine, air temperature, and wind speed.]

11. Hounam, C. E. "Meteorological factors affecting physical comfort (with special reference to Alice Springs, Australia)." International Journal of Biometeorology 11: 151-162, 1967. [After comparing various approximate indexes, the author favors effective temperature, which he illustrates by frequency distributions and comparisons of a number of places.]

12. Gregorczuk, M., and Cena, K. "Distribution of effective temperature over the surface of the earth." Ibid., 145-149. [Maps for January and July.]

13. Terjung, W. H. "Annual physioclimatic stresses and regimes in the United States." Geographical Review 57: 225-240, 1967. [A temperature-humidity index summarized in cumulated form for mapping.]

14. Pugh, L. G. C. E. "Solar heat gain by man in the High Himalaya." Arid Zone Research 24: 325-330, 1964. [Comparison of radiation budgets at 5800 m and low-altitude desert sites. This volume also includes papers on the performance and energy requirements of men in extreme environments.]

[Basic texts that bear on the budgets of organisms, in addition to those cited above, include those by Geiger (item III A-5), Brooks (III A-6), Landsberg (III A-7), and Rose (VI E-1). A number of works deal with energetics in general, e.g., items III B 1-2 and VI A 11 to 16. Radiation as a specific kind of high-energy input is treated in items II A-10 and III C 1-2. General works on effects of pollutants on organisms are references II C11-13 and those in Sec. II E, especially in Stern, II E-11.]

B. Man in the Cold

1. Burton, ɪ . ʟ and Edholm, O. G. Man in a Cold Environment. Baltimore: Williams & Wilkins, 1955, 273 pp. [Very useful review of the advantages and problems of the homeothermic organism and how it must solve the laws of heatflow. Chapters on insulation by body tissues, clothing, and air, and on metabolic production of heat, lead up to approximate procedures for estimating the thermal demand of the environment.]

2. Carlson, L. D., and Hsieh, A. C. L. "Cold." In: The Physiology of Human Survival, O. G. Edholm and A. L. Bacharach, editors. New York: Academic Press, 1965, 15-51. [Heat flow in two systems: from the internal body to the skin, and from the skin to the environment.]

3. Woodcock, A. H. "Clothing and climate." In: Medical Climatology, S. Licht, editor. New Haven: E. Licht, 1964, 557-580. [Disposes of the old notion about "damp-cold" being worse than "dry-cold".]

C. Man in the Heat

1. Hatch, T. "Assessment of heat stress." In: Temperature. Its Measurement and Control in Science and Industry, Vol. 3, Part 3, C. M. Herzfeld, editor. New York: Reinhold, 1963, 307-318.
2. Hertig, B. A., and Belding, H. S. "Evaluation and control of heat hazards." Ibid., 347-355. [An index of the gradient from the skin "down to the thermal level of the environment" (Hatch), and methods for calculating exchanges of radiation, sensible heat, and latent heat, with control measures (Hertig and Belding).]

3. Fox, R. H. "Heat." In: The Physiology of Human Survival, O. G. Edholm and A. L. Bacharach, editors. New York: Academic Press, 1965, 53-79. [Reviews the many indices of heat stress on the body; none is complete.]

4. Lind, A. R. "Physiologic responses to heat." In: Medical Climatology, S. Licht, editor. New Haven: E. Licht, 1964, 164-195. [Heat exchanges, storage in the core and shell of the body, means of thermoregulation, and acclimatization.]

5. Roller, W. L. and Goldman, R. F. "Estimation of solar radiation environment." International Journal of Biometeorology 11:329-336, 1967. [Depletion model for calculating direct and diffuse solar radiation. Cf. reference III C-1.]

D. Some Works on the Budgets of Animals

1. Brody, S. Bioenergetics and Growth, with Special Reference to the Efficiency Complex in Domestic Animals. New York: Reinhold, 1945. [Reprinted 1964, New York: Hafner.] [Chapters 2-3, 13, and 15 deal with energy specifically, with discussion of feed and nutrient energy, growth, and work processes of cattle.]

2. Findlay, J. D. "Veterinary biometeorology." International Journal of Biometeorology (Leiden) 7: 137-143, 1963.
3. Haufe, W. O. "Entomological biometeorology." Ibid., 129-136. [Short reviews of environmental relations of insects and domestic animals.]

4. McNab, B. K. "The metabolism of fossorial rodents: a study of convergence." Ecology 47: 712-733, 1966. [Energy relations of species of burrowing rodents from different climates are associated with burrow temperature, i.e., with its depth. However, diffusion of oxygen from the earth's surface to the burrow also depends on depth; gas and energy exchanges are connected.]

5. Idem. "A model of the energy budget of a wild mouse." Ecology 44: 521-532, 1963. [A nocturnal homeotherm. Heat loss depends on the daily cycles of habitat temperature, activity, and metabolism, and is compared with the animal's energy intake and the energetics of the vegetation cover it lives in.]

[Energy relations of individual animals are also discussed, for certain insects, in items VI B-11 to 14, VII C-6, and VIII A-15. Energy relations of cattle, including metabolism, milk production, and the value of shading, are subjects of papers by Johnson, McDowell, and Bond in "Ground Level Climatology", reference VI A-19. Animal populations figure in Sec. VI A and B.]

E. In The Desert

1. Macfarlane, W. V. "Water and electrolytes of man in hot dry regions." Arid Zone Research 24: 43-53, 1964.
2. Idem. "Merino sheep as desert animals." Ibid., 259-265, 1964. [Budgets of water and salts as influenced by the budget of energy of man and sheep. Excellent syntheses bring out the role of evaporation in an energy budget marked by large radiative-heat load and an incoming flux of sensible heat, with consequences for salt concentrations and water demand. The sheep is benefited by the insultative value of its fleece, which attains a high surface temperature (75 to 85°C) at some distance away from its body and thus increases the rate of outward heat flow.]

3. Edney, E. B. "Animals of the desert." In: Arid Lands, E. S. Hills, editor. London: Methuen, 1966, 181-218. [Water and temperature relations; mammalian adaptations in structure, nutrition, and reproduction; other animals, including locusts.]

4. Idem. Water Relations of Terrestrial Arthropods. New York: Cambridge University Press, 1957. 109 pp.
5. Idem. "Water balance in desert arthropods." Science 156: 1059-1066, 1967. [". . . an extremely successful group of desert inhabitants," by virtue of a wide range of structural and physiological diversities, and in spite of the disadvantage of small size, which reduces the chance of much evaporative cooling in the energy budget.]

6. Handbook of Physiology, Section 4, Adaptations to the Environment, J. Field, editor. Washington: American Physiological Society, 1964. [Contains six review papers on animals in dry heat: Arthropods, desert reptiles, birds, and rodents, ungulates (especially useful chapter), and man, on pp. 451-582. Macfarlane's paper on the ungulates gives a clear description of the heat stresses and provides interesting comparisons of different animals.]

7. Arid Zone Commission. Environmental Physiology and Psychology of Man: Arid Conditions. Reviews of Research. Arid Zone Research 22, 1953. [Another useful volume of this UNESCO series.]

F. Budgets of the Plant Leaf

1. Evans, L. T., editor. Environmental Control of Plant Growth. New York: Academic Press, 1963. [Many good papers on light, and the exchange of carbon dioxide, water, and energy at leaf surfaces, representing some of the best field observations made on plant communities. Several of these papers are individually cited in this outline.]

2. Gates, D. M. Energy Exchange in the Biosphere. New York: Harper and Row, 1962. 151 pp.
3. Idem. "The energy environment in which we live." American Scientist 51: 327-348, 1963.
4. Idem. "Energy, plants, and ecology." Ecology 46: 1-13, 1965. [All these contain much useful material on the nature of radiation and other forms of energy, especially as they enter into transactions of plants and animals. Implications for ecosystems and regional vegetation cover. The second of the three papers, a Sigma XI lecture to induce more biologists to apply physical concepts of heat flow, is particularly good for students to work through.]

5. Raschke, K. "Heat transfer between the plant and the environment." Annual Review of Plant Physiology 11: 111-126, 1960. [Good review paper on energy exchange at leaf surfaces.]

6. Knoerr, K. R., and Gay, L. W. "Tree leaf energy balance." Ecology 46: 17-24, 1965. [Measurements of radiative and turbulent energy fluxes show how leaf temperature mediates inflows and outflows to keep the budget in balance. In strong heat inputs, the rise of leaf temperature far above air temperature creates a heavy demand for water, or may reach the lethal range.]

7. Linacre, E. T. "Calculations of the transpiration rate and temperature of a leaf." Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie B, 13: 391-399, 1964.
8. Idem. "Further studies of the heat transfer from a leaf." Plant Physiology 42: 651-658, 1967. [These papers discuss energy budget and temperature of leaves of crop plants in relation to the resistance to diffusion of water vapor from the leaf in different environments. Cf. ref. VI C-5 on crop relations.]

9. Waggoner, P. E., and Zelitch, I. "Transpiration and the stomata of leaves." Science 150: 1413-1420, 1965. [Behavior of stomata, and the possibility of changing it by biochemical inhibitors, in order to reduce evapotranspiration.]

10. Fritts, H. C. "Growth rings of trees: a physiological basis for their correlation with climate." In: Ground Level Climatology, R. H. Shaw, editor. Washington: American Association for the Advancement of Science, Publication 86, 1967, p. 45-65. [Ring growth seems to be related to leaf temperature, which affects respiration and hence net production.]

[Relations of individual plants to plant communities, and the productivity of plants and communities are also treated in reference III B-4, III D-1 and 2, in references in section VI A (ecosystems), VI B (cases), VI C (atmospheric relations), VI F (corn) and VI G (forest). Reference VIII G-7 discusses the responses of farm plants and animals to possible changes in climate.]

Problems:

1. Calculate heat loss from man by the formulas in references A-2, A-10, B-1, or C-3, for extreme summer conditions in your city. Compare your city with New Orleans during a month in summer by these measures, or by Hounam's comfort index (ref. A-11).

2. Work out the energy budget of cattle in the sun and under shade from Bond's paper in reference VI A-19. From Brody's (ref. D-1) or other information, can you estimate how much the shade is likely to increase the daily weight gain of beef cattle or the daily milk production of dairy cattle? Is it worth while, by providing shade, to feed the animals where the alfalfa is being grown (in hot, sunny interior valleys) rather than truck hay to animals in the environs of the coastal cities where the meat or milk will be marketed? In other words, how does the animal's heat budget enter the competition between hot rural feedlots and cool suburban feedlots?

3. Plot the energy budget of a sheep in the sun, as given by Macfarlane (ref. E-6), and also the profile of temperature through its insulating fleece. What would be the effect of shearing the sheep in summer?

4. Graph the diurnal energy budget of the field mouse memorialized in Reference D-5, showing changes in activity, heat exchanges by radiation and conduction, and evaporative heat exchange. What are the connections between these exchanges and the daily regimes in the mouse house?

5. The radiation budget measured by Knoerr and Gay (ref. F-6) shows radiative heat load on a broad leaf in the open air, from above and below. Graph the radiation budget and other components of the total energy budget (convection and latent-heat flux) in different conditions of air movement. Compare with the budget of a leaf in the indoor environment. Here you see the genuine "greenhouse effect"—a reduction of heat exchange by cutting off ventilation.

UNIT VI. SYNTHESIZING THE BUDGETS OF ELEMENTS OF THE LANDSCAPE: ECOSYSTEMS, FOREST STANDS, CROP FIELDS, AND OTHER HOMOGENEOUS SURFACES

Objectives:

To examine interlocking and interaction among the energy and mass budgets of surface cover types;

To exemplify budget accounting methods at familiar segments of the earth's surface, like meadows or corn fields;

To demonstrate how budget concepts enable the geography student to appreciate and make use of data from glaciology, hydrology, limnology, and oceanography and new ideas about ecosystem dynamics from ecology, by setting these within the framework of the earth's surface;

To benefit from current research in productivity, with its implications on the one hand for a better understanding of the environment of organisms and on the other for man's survival.

Outline: (Two outlines are offered. The first stresses a systematic approach; the second is closely related with cited references.)

Outline A:

A. Properties of ecosystems or other elements of the landscape

Interface properties: albedo, exposure, roughness, and coupling with the atmosphere

Volume properties: capacity to store energy and water; coupling with the substrate

Possible modification of these properties by man's actions.

B. Inputs: amounts, rates, annual cycles or seasonality

Solar radiation, advected energy, precipitation, other forms of matter.

C. Internal redistributions, circulations, and conversions of energy, water, nutrients, contaminants

D. Internal storages of energy, water, other forms of matter

E. Outputs, or yields: Amounts, seasons of harvest

Energy as biological production, as sensible heat, latent heat, radiation

Whole-system energetics in the light of radiative and atmospheric inputs

Water yield as vapor or bulk flow

Whole-system cycling of nutrients or other forms of matter.

UNIT VI

Outline B:

A. Introductory considerations

B. Case studies of landscape elements

Danish grassland; glacier snowfields; marshes (with energetics of fauna); corn fields and other crop lands; forest stands and other wildland systems.

C. Atmospheric coupling; upward relations of ecosystems

D. Substrate coupling and storage capacity

E. Modification of properties by man

Change in albedo, roughness, ventilation, water intake

Cultural and semi-cultural ecosystems.

Commentary:

Not only are budgets of mass and energy found in association in nature, but as the student progresses from individual plants to the ecosystem, the association of symbiotic and competing plants presents a new complication. Nevertheless, these landscape elements are the building blocks of the geographic landscape and region, and their budgets must be examined. As Thornthwaite said,[10] "Any region is a composite of innumerable local climates; the climate of the ravine, of the south-facing slopes, of the hilltop, of the meadow, of the cornfield, of the woods, of the bare rocky ledge. Both the heat and moisture exchange vary from the ravine, to the hilltop, and to the rocky ledge, because of the variation in the physical characteristics, position, exposure, and aspect of these diverse surfaces." It is the budgets of these individual surfaces[11] that in spatial interaction comprise the climate of the earth.

Fortunately, other sciences also have taken an interest, for their own reasons, in the budgets of some of these surfaces. Glaciologists long ago began to study glacier snow fields, because they wanted to know the mass budgets of the glaciers themselves as a key to changes in large-scale climate. Hydrologists have studied mountain snow fields, because they wanted to determine the rates at which the snow might melt and enter the drainage networks they were managing. Limnologists and oceanographers have studied the budgets of lakes and the ocean surface for biological reasons, as well as to determine the net balance of income and outgo of water. The science most recently beginning to study landscape elements of the size considered in this unit is botany, after the concept of the ecosystem was

10. C. W. Thornthwaite, "The task ahead." *Annals of the Association of American Geographers 51*: 345-356, 1961. A presidential address.

11. The term "landscape element" is used here as a general designation of an element of the variegated scene one finds in nature. It is taken to include both biological and non-biological types of surface cover, such as ecosystems, corn fields, snow-covered meadows. The criterion for any of these is areal uniformity and uniform receipt of energy and matter from the sun and atmosphere.

developed and opportunities became available to measure energy and mass inputs and outputs of the whole system. Agronomists and now foresters, as applied ecologists, are studying energy and mass budgets of biological systems of a more or less cultural origin, which offer the advantage of relative uniformity to the sampling observer. Some of these studies have been cited in preceding units, if they seemed particularly useful either for energy-budget or for water-budget studies. Those cited in this unit offer both budgets, and some also present data on exchanges of matter other than water, e.g., carbon dioxide.

Few generalizing studies have yet been written of all the kinds of landscape elements that are being studied in the field. However, either of the two outlines offered for this unit should suffice as an integrating framework for instruction.

Few of the landscape elements considered in this unit are indefinite or extensive in size. The next level in a quasi-hierarchy, then, would be a landscape of juxtaposed ecosystems, i.e., a mosaic landscape. The budgets discussed in this unit give way to budgets of more complicated patterns, which, however, can be derived from those of the individual ecosystems.

References:

The list begins with a considerable number of references that might be useful in orienting a teacher in the concepts of ecosystems and their circulation of energy and matter, insofar as these are related to climatic budgets. Several of these have been written by geographers for geographers, and are highly recommended.

There are fewer comparative analyses of the budgets of ecosystems and landscape elements in different parts of the world than might be expected. This is largely, perhaps, because many investigations for immediate ends are not complete with respect to all components of the budget. For example, studies of drainage-basin hydrologies usually fail to measure the true delivery of rain or snow to the forest canopy, the outflow of ground water, or the storage of water on leaves or litter. Without information on these fluxes of water it is difficult to determine why one basin yields a different output of stream flow than another, and the task of generalizing to reach valid and useful results is difficult. Studies of glacier heat flows and melting, where the budget concept came early into operational use, have tended on the other hand to be reasonably complete (see item VI B-5). As a result, the glaciological literature contains useful comparative studies of the relative importance, say, of radiative vs. advective heat inputs in different parts of the world (as in item VI B-7).

Biological systems, being more complicated with regard to their internal translocations, storages, and conversions of energy than glacial snow fields, are less completely measured in the field, and comparative analyses are still less common. It is hoped that this situation will be improved by the joint efforts of the International Biological Program, which puts considerable stress on productivity and energy flows and provides standards for complete field observation.

Section B contains case studies, mostly of an exemplary nature, that I have found invaluable in teaching, in ways suggested by their annotations.

Following these, in Section C, are references on the coupling of ecosystems with the atmosphere, with cross-references to papers from micrometeorological investigations cited in earlier units of the outline. Section D lists references on the coupling of ecosystems with their substrates. Soil originates as a result of the activity at the overlying surface and the resulting vertical movement of water, heat, and minerals, which is promoted by the presence of plant roots. Your attention is invited to the large number of cross-references on the couplings of surface with atmosphere and with substrate.

Man's changes of the face of the earth are most evident at the scale of the landscape element. With the technology of the past, his efforts were concentrated on cultivating crop fields, logging mountain slopes, and the like, replacing the ecosystems previously in a region with those that he wanted to foster for the sake of special yields. References are therefore presented in Section E to studies of alterations of the earth's surface over areas of the scale discussed in this unit. This is followed, as an illustration, by a group of studies of corn fields in the Middle West and elsewhere. Agricultural meteorologists have given concentrated attention to these systems, with results that are useful in exemplifying interaction of the mass and energy budgets. Forest meteorologists are beginning to follow suit, and a few of their papers end the list.

Deficiencies in the list reflect the omission of excellent studies that happen to be reported in a language other than English. Excluded by this criterion are such pieces of work as the thorough energy and water studies of forest at the Institute of Geography in Moscow and at the University of Munich, of agricultural crop land in the Institute of Agricultural Research in Tokyo, the results of the comprehensive investigations of tree-line ecosystems, land-management units, and microclimates in the Alps. References to them can be found, however, in the review items that are cited. Meanwhile, the citations that follow may serve as introductions and appetizers for these other investigations.

A. General

1. Edwards, K. C. "The importance of biogeography." Geography 49: 85-97, 1964. [Studying the soil-vegetation complex under actual conditions of climate "enhances the unity of geography."]

2. Stoddart, D. R. "Geography and the ecological approach. The ecosystem as a geographic principle and method." Geography 50: 242-251, 1965. [The ecosystem "brings together environment, man, and the plant and animal worlds within a single framework, within which the interaction between the components can be analyzed." Its operation, which is a "continuous through-put of matter and energy" is analogous to a communications net and the goods flowing through it.]

3. Odum, E. P., with collaboration of Odum, H. T. Fundamentals of Ecology, 2d edition. Philadelphia: Saunders, 1959. 546 pp. [A basic reference on ecosystems, their energy flows, and productivity.]

4. Billings, W. D. Plants and the Ecosystem. Belmont, Calif.: Wadsworth, 1964. 154 pp. [A paperback stressing environment, ecosystem dynamics, and their relation to man's welfare.]

5. Odum, H. T. "Ecological potential and analogue circuits for the ecosystem." American Scientist 48: 1-8, 1960. [Electrical analogs of ecosystems lead to a number of interesting insights.]

6. Lavrenko, Ye. M. "Moisture and heat factors and the geography and ecology of the plant cover." Soviet Geography 2, No. 6: 3-8, 1961. [Perspective on the nature of the relations between two components of climate and two scales of vegetation, with a programmatic statement of research approaches.]

7. Lemon, E. "Energy and water balance of plant communities." In: Environmental Control of Plant Growth, L. T. Evans, ed., New York: Academic Press, 1963, 55-78. [Budgets of radiation and water, and two subsidiary processes—photosynthesis, and efficiency of water use.]

8. Wijk, W. R. van, editor. Physics of Plant Environment, 2d edition. Amsterdam: North-Holland, 1966. 382 pp. [Includes soil climate.]

9. Vries, D. A. de "The physics of plant environments." In: Environmental Control of Plant Growth. L. T. Evans, ed., New York: Academic Press, 1963, 5-22. [Brief account of "what happens to the solar radiation and the rainfall that reach the earth's surface."]

10. Wilsie, C. P. Crop Adaptation and Distribution. San Francisco: Freeman, 1962. 448 pp. [Application of ecosystem and productivity ideas to systems of cultivated vegetation.]

11. Olson, J. S. "Energy storage and the balance of producers and decomposers in ecological systems." Ecology 44: 322-331, 1963. [Input-output models of build-up and decomposition of organic matter, and the resulting level of storage of energy.]

12. Odum, E. P. "Organic production and turnover in old field succession." Ecology 41: 34-49, 1960. [Changes occur in structure of vegetation after the abandonment of a cultivated field, but functions and productivity stay about the same. Would seem to have implications for swidden and other land-management systems.]

13. Pearson, O. P. "Metabolism and bioenergetics." Scientific Monthly 66: 131-134, 1948. Reprinted in Readings in Population and Community Ecology, W. E. Hazen, ed. Philadelphia: Saunders, 1964. 226-229. [An interesting note on the way animals degrade energy, with an acre of Pennsylvania forest as an example, to a point where it is "beyond recall by the plant and animal kingdoms." The Amerinds degraded little energy, but the Anglos are profligate.]

14. Slobodkin, L. B. "Energy in animal ecology." Advances in Ecological Research 1: 69-101, 1962. [Role of energy in ecology, and energy budgets of populations in given environments.]

UNIT VI

15. Englemann, M. D. "Energetics, terrestrial field studies, and animal productivity." Advances in Ecological Research 3: 73-115, 1966. [Development of ideas about energy flows in ecosystems.]

16. Newbould, P. J. "Production ecology and the International Biological Programme." Geography 49: 98-104, 1964. [The first large-scale attempt to examine "the functional characteristics of ecosystems," not merely their taxonomy or physiognomy. The program, following on the International Geophysical Year and the International Hydrological Decade, should result in new fundamental knowledge of the basic relations with solar radiation and other energetic aspects of climate.]

17. Simmons, I. G. "Ecology and land use." Transactions of the Institute of British Geographers 38: 59-72, 1966. [Ecosystem ideas provide means of examining inputs and levels of energy and nutrients, and also for seeing the roles of man as both a consumer in the system and a director of it—thus "assessing the cultural factor in land use." A paper for geographers to take to heart.]

18. Baumgartner, A. "The heat, water and carbon dioxide budget of plant cover: methods and measurements." Arid Zone Research 25: 495-512, 1965. [Valuable review of concepts and techniques in research on the combined budget.]

19. Shaw, R. H., editor. Ground Level Climatology. Washington: American Association for the Advancement of Science, Publication 86, 1967. 395 pp. [Papers from a symposium, chiefly on climatic effects on crops and livestock. Several papers employ energy-budget ideas.]

20. Wilson, J. W. "Ecological data on dry-matter production by plants and plant communities." In: The Collection and Processing of Field Data, A CSIRO Symposium, E. F. Bradley and O. T. Denmead, editors. New York: Interscience, 1967, p. 77-123. [Good comparative study of productivity in the light of radiation and mass-exchange budgets of many plant systems.]

21. Baer, J. G. and Worthington, E. B. "Exploring the resources of the biosphere." Geographical Journal 133: 435-444, 1967. [Examples of work of the IBP, especially in Africa.]

[General references on ecosystems that appear in other units of this outline include III A-5 to 10, IV A-1, and IV A-13 and 14. References in Section III B are on the ecosystem idea and its relation with such other field sciences as geography. Relations with atmospheric conditions are discussed in many articles cited in Unit III and IV. Effects of changes in the atmosphere, where natural, are included in references in Unit VIII G, and where specifically the results of man's doings, in references VIII G-10 to 12, V A-9, and in Sections II C, D, and E.]

B. Case Studies

1. Aslyng, H. C., and Nielsen, B. F. "The radiation balance at Copenhagen." Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie B, 10: 342-358, 1960.
2. Aslyng, H. C. "Evaporation and radiative heat balance at the soil surface." Ibid., 10: 359-375.
3. Kristensen, K. J. "Temperature and heat balance of soil." Oikos 10: 103-120, 1959. [These three studies provide a comprehensive account of the annual changes in the budget of energy and water at a grass-clover field in a North European grassland economy. Good problems for students can be worked out from the monthly figures of input and outgo of the heat and water fluxes, and a sequence of processes can be presented to them that leads up to measures of the productivity—375 calories per square centimeter in an average growing season. Implications of this production for exports of cheese, ham and butter in Denmark's balance of trade can be added by the teacher. Ten-year summaries of this unique combination of measurements of heat and water fluxes have been published in recent issues of the Yearbooks of the Royal Agricultural University and in Acta Agriculturae Scandinavica.]

4. Long, I. F., Monteith, J. L., Penman, H. L., and Szeicz, G. "The plant and its environment." Meteorologische Rundschau 17: 97-101, 1964. [One day in the budgets of a barley field in England: careful measurements of the surface budget of energy, the profiles of radiation, ventilation, and carbon dioxide penetration into the crop stand, and the profiles of temperature and humidity downward from the free air, through the crop and into the soil.]

5. Wallén, C. C. "Glacial-meteorological investigations on the Kårsa Glacier in Swedish Lappland 1942—1948." Geografiska Annaler 30: 451-672, 1949. [A study in the classic Scandinavian tradition of the energy and water budget of a glacier. The fluxes of energy and water are described in association with factors that intermesh to bring about a shrinkage of the glacier. A long series of summer measurements, which illustrate how much work goes into a Scandinavian doctorate, provide good teaching material. Cf. a later investigation, P. C. Dibben, "Heat-balance study on Sørbreen, Jan Mayen," Journal of Glaciology 5, No. 42: 793-803, 1965.]

6. Wood, W. A. "The Icefield Ranges research project." Geographical Review 53: 163-184, 1963. [Mass and energy budgets included.]

7. Hoinkes, H. C. "Glacial meteorology." In: Research in Geophysics, Volume 2, H. Odishaw, editor. Cambridge, Mass.: Massachusetts Institute of Technology Press, 1964, 391-424. [Review of mass and heat budget studies on many glaciers, with comparisons. Emphasizes the importance of recording albedo over long periods.]

8. Hanson, K. J. "Some aspects of the thermal energy exchange on the south polar snow field and Arctic ice pack." Monthly Weather Review 89: 173-177, 1961.

9. Hanson, K. J., and Rubin, M. J. "Heat exchange at the snow-air interface at the South Pole." Journal of Geophysical Research 67: 3415-3424, 1962.

10. Lettau, H. H., Dalrymple, P. C., and Wollaston, S. H. "South Pole surface energy budget." International Association of Scientific Hydrology, Publication 61: 18-23, 1963. [Three studies on the energy budget of a site on an ice cap. See also Sec. VIII E and III E-5.]

11. Smalley, A. E. "Energy flow of a salt marsh grasshopper population." Ecology 41: 672-677, 1960.

12. Teal, J. M. "Energy flow in the salt marsh ecosystem of Georgia." Ecology 43: 614-624, 1962. [Productivity of marsh grass, and energy flow to herbivores (grasshoppers), decomposers, and larger animals. The completeness of these budgets lies in their extension right through all the kinds of organisms present in the landscape element.]

13. Golley, F. B., and Gentry, J. B. "Bioenergetics of the southern harvester ant, Pogonomyrmex badius." Ecology 45: 217-225, 1964. [Energy conversion in the whole population, in unit-area terms; daily food consumption is about 0.01 calories per square centimeter.]

14. Golley, F. B. "Energy dynamics of a food chain of an old-field community." Ecological Monographs 30: 187-206, 1960. [Energy flows in a community that results from the cultural process of land abandonment.]

15. Mather, J. R., editor. "Factors of the heat and water balance of different surfaces." Publications in Climatology 20, (No. 2): 173-273, 274-429, 1967. [Valuable critique of surface budgets in general, and a long series of well-described observations near the Thornthwaite Laboratory of Climatology in New Jersey. Part 1 contains papers by Mather, R. A. Muller, R. T. Field, and G. A. Yoshioka; Part 2 contains data.]

16. Aulitzky, H. "Significance of small climatic differences for the proper afforestation of highlands in Austria." In: Forest Hydrology, W. E. Sopper and H. W. Lull, editors. New York: Pergamon Press, 1967, 639-653. [Brief well-illustrated summary of a long interdi ciplinary investigation on tree-line ecosystems in the Alps that need to be restored to a medieval and more rational land-use pattern in order to reduce avalanching. Ecologists, engineers, meteorologists, plant physiologists, foresters, hydrologists, pedologists, mycologists, snow scientists—all contributed to a true understanding of the energy and water budgets of these vulnerable, important landscape elements. Scores of papers have been published from the investigation but are omitted here because they are not in English; the cited paper by Aulitzky will have to serve as introduction to this major accomplishment in biophysical geography.]

C. Atmospheric Relations

1. Saeki, T. "Light relations in plant communities." In: Environmental Control of Plant Growth, L. T. Evans, ed., New York: Academic Press, 1963, 79-94.
2. Tanner, C. B. and Lemon, E. R. "Radiant energy utilized in evapotranspiration." Agronomy Journal 54: 207-212, 1962. [Two papers on radiation inputs.]

3. Idso, S. B., Baker, D. G., and Gates, D. M. "The energy environment of plants." Advances in Agronomy 18: 171-218, 1966. [Plants and the energy budget, in relation with productivity. Cf. references V F-2 to 4.]
4. Monteith, J. L., and Szeicz, G. "The carbon-dioxide flux over a field of sugar beet." Quarterly Journal of the Royal Meteorological Society 86: 205-214, 1960. [Inflow of CO_2 depends on intensity of solar radiation. For related work, see refs. II C-5 (forest) and VI B-4 (barley).]

5. Linacre, E. T. "Climate and the evaporation from crops." Journal of the Irrigation and Drainage Division, American Society of Civil Engineers, Vol. 93, No. IR 4, 61-79, 1967. [While solar radiation energizes evapotranspiration, the ratio between the two varies, and should be used with caution in engineering empiricisms. Cf. Linacre's work on leaves, refs. V F-7 and 8; also cf. Sec. IV B.]

[Coupling of ecosystems with the overlying atmosphere, and their reception of inputs of energy, water, and so on form a major part of works on micrometeorology: see items in I D and E. Inputs of advected energy as sensible heat are discussed in items VII B-1 to 3. Inputs of carbon dioxide are discussed in item II C-4, of pollutants and biocides in II C-11 to 13. The input of radiative energy is described in items III C-1 to 3, and V F-2 to 4. The input of precipitation is described in IV E-7 to 14.

Alterations in inputs by some kind of weather or climate modification are considered in VIII G-10 and 11. The output of water vapor is the subject of references in IV B. The degree of coupling between plant association and atmosphere is indicated by such properties as the albedo, roughness, and temperature of the active surface (items III C-9 to 11, III D-1 to 3, and III E-2).]

D. The Soil Phase of the Ecosystem

1. Russell, M. B., coordinator. "Water and its relation to soils and crops." Advances in Agronomy 11: 1-131, 1959. [Excellent review, pointing out that "water use by crops is primarily an energy-dependent process" and concluding with discussion of the soil-plant-water system and ways of managing it.]

2. Buckman, H. O., and Brady, N. C. The Nature and Properties of Soils, 6th edition. New York: Macmillan, 1960. 567 pp. [Several chapters on the water budget in soil; somewhat less on the energy budget. Good material to work up into lectures for elementary geography students. (Earlier editions also bore the name of T. L. Lyon.)]

3. Philip, J. R. "Evaporation, and moisture and heat fields in soil." Journal of Meteorology 14: 254-266, 1957. [Identifies three stages in the evaporation of water from a drying soil body.]

4. Gerasimov, I. P. "The moisture and heat factors of soil formation." Soviet Geography 2, No. 5: 3-12, 1961. [Effects of the energy and water budget on the climate of the soil and the circulations that form it.]

5. Arkley, R. J. "Calculation of carbonate and water movement in soil from climatic data." Soil Science 96: 239-248, 1963.
6. Thornthwaite, C. W., Mather, J. R., and Nakamura, J. K. "Movement of radiostrontium in soils." Science 131: 1015-1019, 1960. [These papers use the water budget to determine amounts of downward movement of water, from which the transport of other forms of matter to lower horizons can be established.]

[Coupling of ecosystems with the substrate, and the heat-water budgets of their soil component are cited also in items III D-4 to 7, IV F-2 to 4 and F-7 to 13, the last in particular dealing with the important parameter of soil moisture and its climatological probabilities. Item IV F-18 is also a good source on soil moisture.]

[The energetics of ecosystems is associated with the closeness of their coupling with atmosphere and subtrate. It involves the internal distribution of radiant energy (III C-3, for example), energy storage in the substrate (III D-4 to 7 for soil, D-13 to 16 for lakes), and in plant tissue (VII A-10). Conversions of energy are treated in references VI B-5 to 10 and VII D-6 to 8 for snow and glacier landscape elements. They are described in items IV B-8 and 11 and V F-2 to 4 for simpler biological systems, and in III B-1 and 2, and sections V C and V D for more complicated systems.]

[The outputs of ecosystems or landscape elements may move into the atmosphere as oxygen (reference II C-6), as sensible heat (see references in Section III E, VII A-1 and 2, and VII B-1 to 3), or as latent heat (references in Section IV B, for example; that by Thornthwaite and Hare [IV B-15] in particular). Output may leave as liquid water, sometimes of great economic value as such or as potential power (Sec. VII D and VIII B, C, and D), or as a mixture of water and other substances (references VII E-1 to 18) especially items 17 and 18). Output may leave as wood (VII A-10) or other kinds of plant tissue (Section VI B, VIII B-1 to 6), representing stored energy. Changes in output that result from changes in input or operating conditions sometimes are a threat; for example, see items VIII G-6 to 8.]

E. Modifications by Man

1. Rose, C. W. Agricultural Physics. New York: Pergamon Press, 1966. 226 pp. [Clear exposition of processes at and near the surfaces of crop land. Chapters 1 to 3, on the physical environment of agriculture, bridge "the gap between the secondary standard and . . . current research literature." Chapter 8 discusses water movement in the soil-plant-atmosphere system. Excellent background

for a person teaching energy and water budgets and for students interested in the physics of geography or in agricultural geography.]

2. Dreibelbis, F. R., and Amerman, C. R. "Land use, soil type, and practice effects on the water budget." Journal of Geophysical Research 69: 3387-3393, 1964. ["Practice" refers to the prevailing or improved systems of managing the corn-hay-oats rotation in the Appalachian Plateau. Coshocton data also in Ref. IV B-13.]

3. Rutherford, J. "Double cropping of wet padi in Penang, Malaya." Geographical Review 56: 239-255, 1966. [Increased management of the water input, in association with biological, cultural, and economic factors.]

4. Geertz, C. Agricultural Involution: The Process of Ecological Change in Indonesia. University of California Press, 1963. 176 pp. [A good example of ecosystem analysis: (a) tropical forest and swidden are both closed-cover systems in which matter and energy circulate rapidly between living forms; with comments on the role of burning; (b) a wet-rice sawah is a stable and productive system, almost infinitely capable of receiving additional inputs of labor. "A Javanese peasant's terrace... is both a product of an extended historical process of cultural development and perhaps the most immediate constituent of his 'natural' environment."]

5. Hogg, W. H. "Meteorology and agriculture." Weather 19: 34-43, 1964.
6. Idem. "Meteorology and horticulture." Ibid. 19: 234-241.
7. Idem. "Meteorological factors in early crop production." Ibid. 22: 84-94, 115-118, 1967. [Reviews of problems in the exchanges of energy, water, and momentum at cultural surfaces, and the value of irrigation, wind shelter, and other practices in meeting them.]

8. Smith, D. D., and Wischmeier, W. H. "Rainfall erosion." Advances in Agronomy 14: 109-148, 1962. [Mechanics of soil damage to culturally bared land in rainstorms.]

9. Chepil, W. S., Siddoway, F. H., and Armbrust, D. V. "Climatic factor for estimating wind erodibility of farm fields." Journal of Soil and Water Conservation 17: 162-165, 1962. [The factor is a combination of cubed wind speed and Thornthwaite's P-E index, for comparison with edaphic and vegetation parameters of erodibility. Map and frequency distribution. See also items in Sec. I G.]

10. Moody, J. E., Jones, J. N., Jr., and Lillard, J. H. "Influence of straw mulch on soil moisture, soil temperature and the growth of corn." Proceedings of the Soil Science Society of America 27: 700-703, 1963. [How an artificial cover affects the energy and moisture budget of soil.]

11. McCalla, T. M., and Army, T. J. "Stubble mulch farming." Advances in Agronomy 13: 126-196, 1961. [A system of crop-residue management and its effects on wind erosion, water fluxes, soil temperature, and yields.]

12. Bartholic, J. F., Runkles, J. R., Stenmark, E. B. "Effects of a monolayer on reservoir temperature and evaporation." Water Resources Research 3: 173-179, 1967. [A change in the water budget has effects on the heat budget. See ref. IV B-14.]

[Alterations in atmospheric conditions are discussed in citations in section VIII G; alterations in surface conditions in items III F-2 and 3, and IV B-2. For microenvironments where ecosystems early were altered for man's profit, see references VII A-5 to 7, and for a profound alteration, rice terraces, see the review by Inoue (I G-1).]

F. Corn Fields as Ecosystems

1. Denmead, O. T., Fritschen, L. J., and Shaw, R. H. "Spatial distribution of net radiation in a corn field." Agronomy Journal 54: 505-510, 1962.
2. Yao, A. Y. M., and Shaw, R. H. "Effect of plant population and planting pattern of corn on the distribution of net radiation." Agronomy Journal 56: 165-169, 1964.
3. Allen, L. H., Yocum, C. S., and Lemon, E. R. "Photosynthesis under field conditions, Part 7, Radiant energy exchanges within a corn crop canopy and implications in water use efficiency." Agronomy Journal 56: 253-259, 1964. [Cf. earlier parts.]
4. Pavlov, A. V., and Ustenko, G. P. "The heat balance and radiation regime of corn crops." Soviet Geography 7, No. 2: 44-57, 1966.
5. Swanson, E. R., and Tyner, E. H. "Influence of moisture regime on optimum nitrogen level and plant population for corn: a game theoretic analysis." Agronomy Journal 57: 361-364, 1965. [Based on soil-moisture expectancies during critical growing period.]
6. Doll, J. P. "An analytical technique for estimating weather indexes from meteorological measurements." Journal of Farm Economics 49: 79-88, 1967. [These papers are a sampling of studies on the interplay of energy, CO_2, and water budgets in a particular crop. This approach gives a means of evaluating the effects of density and spatial geometry of the plant population, fertilization, and fluctuations in water input, in both physical and economic terms. They would appear to have important implications for agricultural geography. For other references to budgets of corn fields, see VI E-10, VII A-5 to 7 for Mesoamerica and IV F-11 and 12 and VII E-2 for Iowa.]

G. "Wildland" Ecosystems

1. Ovington, J. D., and Heitkamp, D. "The accumulation of energy in forest plantations in Britain." Journal of Ecology 48: 639-646, 1960.
2. Ovington, J. D. "Quantitative ecology and the woodland ecosystem concept." Advances in Ecological Research 1: 103-192, 1962. [The dynamics of water, energy, organic matter, and nutrient elements in the system exemplified by a forest stand—"the most complex and massive of all terrestrial communities," and the most extensive in the geographic landscape.]

3. Hellmers, H. "An evaluation of the photosynthetic efficiency of forests." Quarterly Review of Biology 39: 249-257, 1964. [Probably the most efficient converters of energy on the earth's surface.]

4. Knoerr, K. R. "Contrasts in energy balances between individual leaves and vegetated surfaces." In: Forest Hydrology, W. E. Sopper and H. W. Lull, eds., New York: Pergamon Press, 1967, 391-401. [Making the transfer from leaves to vegetation cover.]

5. Pereira, H. C. "Effects of land-use on the water and energy budgets of tropical watersheds." Ibid. 435-450. [Conversions of wildland vegetation in East Africa to softwood and tea plantations.]

6. Miller, D. H. "Sources of energy for thermodynamically-caused transport of intercepted snow from forest crowns." Ibid., 201-211. [It takes energy to move matter from one place to another; snow is no exception.]

7. Food and Agriculture Organization, Forest Influences. FAO Forestry and Forest Products Studies, 15, Rome: 1962. 307 pp. [Water budget of forest is discussed by Hoover, and the effect of trees on momentum exchange at the surface by van der Linde.]

8. Rowe, P. B., and Colman, E. A. Disposition of Rainfall in Two Mountain Areas of California. U. S. Department of Agriculture, Technical Bulletin 1048, 1951. 83 pp. [Data on percolation, evapotranspiration, and runoff.]

9. Muller, R. A. "A critical review of energy and water balance analyses of various land cover types." Publications in Climatology 20 (2): 199-214, 1967. [The radiation budget and energy budget are described and illustrated for certain types of surfaces, especially coniferous forest plantations in snowy country.]

10. Denmead, O. T. "Evaporation sources and apparent diffusivities in a forest canopy." Journal of Applied Meteorology 3: 383-389, 1964. [The interplay of radiation, sensible heat, and latent heat in a zone of considerable depth—the foliage of a pine plantation.]

[Investigating the energy, carbon dioxide and water budgets of forest stands presents problems of scale not met with investigations on low vegetation. So in spite of the great areal extent and productivity of forest formations in most parts of the world and their significance in producing water, fiber, animal habitat, and amenity, comprehensive budget studies are few. The turbulent fluxes have been most refractory; but without reliable determinations of latent-heat flux, energy budgets can be only approximate. More important, without reliable determinations of evapotranspiration, and also of moisture input to forest from precipitation, most water budgets of forested drainage basins must be regarded as tentative, though they can serve for teaching purposes. English-language summaries of work by Baumgartner (references VI A-18 and VII A-1), Rauner and others (VII A-2), and Aulitzky (VI B-16) may serve as guides to their other publications. Books by Colman (IV A-11) and Reifsnyder and Lull (III C-3) contain budget material and current investigations are going on at such universities as Yale, Duke, and

Syracuse. Some material on budgets of forest stands that are intermingled with areas of lower vegetation is referenced (VII A-10, B-3, and D-8) in the unit on landscape mosaics, which follows.]

Problems:

1. The three papers on the grassland near Copenhagen (refs. B-1 to 3) give mean monthly figures for major energy and water fluxes over a five-year period, an unusual body of data, from which many problems can be derived. Seasonal changes, in particular, show up clearly and well explained in physical terms. There is, for example, the export of sensible heat in summer and its import in winter in mild air off the North Atlantic with its tremendous capacity for energy storage, which extends the growing season well into winter. How can we define the value of the marine exposure? A series of problems has been worked up from these data by C. E. Williams, and, if available, are highly recommended, both for giving students practice in working with budget computations and also for showing how the fluxes interact and are distributed through the year in response to the dominating change in solar radiation.

2. Compare budgets of energy at the Kårsa glacier in several of the summers in which Wallén took records (ref. B-5). How much do summers differ one from another? Compare one of them to the energy budget at the South Pole snow field (ref. B-8 to 10).

3. Work out midday energy budgets of one of the corn fields described in references in Section F. Compare fields in Iowa, New York, and the Ukraine. Compare corn and barley fields (ref. B-4).

4. Compare productivity of vegetation in the Copenhagen case with that of marsh vegetation (B-11 and 12), ecosystems presented in Odum's book (A-3) and energy fixed by forest, as reported by Ovington (refs. G-1 and 2), Hellmers (G-3), and Newbould (A-16). Where is productivity greatest?

5. Graph seasonal regimes of water deficit and surplus from data tabulations published by the Thornthwaite Laboratory of Climatology (vols. 15-17). Take a local region, one other in the United States, and one elsewhere in the world, according to student interests.

6. From the references on the role the ecosystem idea can play in geography (refs. A-1, 2, 3, 6, 17), write a critique of the differences and similarities in the biological and the geographic approaches to nature.

UNIT VII. SYNTHESIZING THE BUDGETS OF MOSAIC LANDSCAPES

Objectives:

To recognize diversity and differentiation at the earth's surface, and express it quantitatively in terms of differences in energy and mass budgets of adjacent landscape elements;

To examine spatial interaction among intermingled ecosystems or landscape elements, as shown by the diffusion, local movement, or concentration of energy, water, or other forms of matter;

To see economic and cultural aspects of local transports of mass and energy and of landscape elements affected by them, e.g., flood plains.

Outline:

A. Sources of contrast among ecosystems or elements of a mosaic landscape

Differences in albedo, roughness, and atmospheric coupling

Differences in storage capacity and coupling with substrate.

B. Local advection between landscape elements

Transport of sensible heat and water vapor

Transport of matter of biological significance

Movement of disturbances in the air stream.

C. Overland movement of water and its collection into a drainage network

Partition of incoming water into infiltrated water and surface run-off; movement of water over slopes and into channels.

Detaching, transport and deposition of soil particles

Channel flow of sediment-bearing water

Formation of flood plains; their economic and cultural advantages and disadvantages.

Commentary:

After recognizing and evaluating the energy and mass budgets at individual surface elements of the earth, such as corn fields, irrigated fields, lakes, forest stands, and so on, the student's next step is to note that these homogeneous elements usually are not infinite in horizontal extent. Some few, like the snow field of the south polar ice cap, approach this state, but most are soon limited where they meet contrasting types of surface. The cause for the change in surface type may be a change in soil body, drainage conditions, radiative or atmospheric microclimate, or in some cultural activity like crop rotation, which ensures the individual fields of corn, alfalfa, and oats in a COH area will seldom be larger than 60 to 80 acres. To designate the resulting repetitive patterns of ecosystems or landscape elements, the term "mosaic landscape" is introduced here. Examples would be almost any farming region that is not a monoculture, or the assemblage of slopes of different aspect, vegetation cover, and soil moistness that makes up a small drainage basin.

Whatever the reason for intermingling of individual landscape elements or ecosystems over the surface of the earth, so visible from an airplane, the consequence is an intermingling of diverse budgets of energy and mass. The further consequence of these contrasts is that a multitude of interactions, local movements of energy, water, sediment, and so forth, start up to transport the surplus in one budget to the deficit in another. Some of these movements take place at the surface, some below it, and some in the local atmosphere. Some escape the eye and may not be measured; herein lies one of the most difficult problems in urban pollution—how do the emissions from many source areas diffuse through the atmosphere of the city? A few organized circulations, like breezes around small lakes, can generally be recognized but represent only a small fraction of the local movements in the atmosphere.

Pollutants and other types of matter move in the local atmosphere, as do pollen, spores, and other plant effluents that are also allergens. There are analogous movements of water vapor and sensible heat from one element to another. Warmth is carried from dry, hot desert surfaces over adjacent moist, cool irrigated crop land, or from dark, absorbing pine foliage to adjacent cold snow-covered meadows. Substantial amounts of energy are thus transported. Desert air flowing over irrigated alfalfa may bring enough energy to increase its evapotranspiration by a quarter or more, so that its energy consumption is larger than the surplus of energy in the radiation budget. This "oasis effect" alters the energy budgets of both the giving and the receiving surfaces.

At the earth's surface, horizontal flows of dust, snow, and particularly bulk water often occur. The overland flow of water during a rainstorm is an essential factor in development of the hydrograph, i.e., the response of the slopes and channel network of a drainage basin to a rain, and is discussed at length in hydrology texts.

Strong overland flow detaches and carries soil particles. The mixture of water and suspended sediment represents an important transport of mass between elements of a landscape mosaic. Deposition of alluvial material below the level a stream attains at its mean annual flood forms a flood plain, which exemplifies transport of matter among landscape elements. The attractiveness of flood plains for settlement stems in part from continuing inputs of water and fresh sediment, as well as their level surfaces. The question of how to avail ourselves of their advantages without paying too great a cost has been investigated by geographers at the University of Chicago, under the leadership of G. F. White. Excellent studies of a flood plain in Australia—that of the Hunter River—and its tributary uplands represent a rare blending of hydrology, regional economics, and geography, but most, unfortunately, are not generally available in this country and only three are cited here.

If the teacher wants to stress energy relations in the course instead of those of water or other substances, and is pressed for time, he might shorten this unit. Its role in the course organization is to present events on a scale intermediate between the ecosystem and the meteorological region. Phenomena at this scale best can be illustrated, in the present state of our knowledge, by water movements in small drainage basins—the movement of excess water and displaced soil from upland slopes into drainage networks and river flood plains. A drainage basin, created by the activity of a drainage network, contains, by the very nature of its formation, slope facets of different aspects. It is thus at a hierarchical level higher than that of the individual slope facet, which is only an element of the visible landscape.

At this scale, water transports are measured more fully than those of energy. If the course is to emphasize energy conversions and exchanges the teacher can go quickly from those that occur in ecosystems and local habitats to those on a scale of 10^5 to 10^6 square kilometers. He should mention the visible heterogeneity of the landscape and the implied mingling of diverse local climatic budgets, at least to the extent of making students aware of another manifestation of spatial interaction, one of the themes of the course. A brief discussion of energy flows within mosaic landscapes can be given from material in the first two sections of the list of references.

In the next teaching unit, several mosaic landscapes that may differ for geologic or other reasons, but that all come under the same wide-scale inputs of radiation and precipitation from the atmosphere, are grouped to form a larger areal unit. Energy and mass budgets may again be cast for this larger entity.

References:

Synthesizing and generalizing studies about mosaic landscapes are relatively few, but many case studies illustrate the intermingling of different elements and cover types at the earth's surface. Most of these are at scales for which spatial interaction is readily visualized. Many contain generous amounts of numerical or graphical material that is good for use in the classroom and for problems.

The first references illustrate the nature of mosaic landscapes and the contrasts found within them, as well as some of their cultural contexts. References in Sections B and C present information about local movement of air-borne energy, water vapor, and aerosols among the contrasting elements of mosaics, and show how widely properties can diffuse through the atmosphere. (See also references in Unit II, especially Sec. II D and II E.)

References of Section D deal with a widely studied phenomenon—the flow of water over the ground. It may move only to a different landscape element and there infiltrate into the soil. In humid lands, however, it becomes concentrated into drainage channels, and once in this network is further concentrated into streams that move long distances. The two phases, overland flow and channel flow, are distinct but often studied together in flood-hydrograph analysis. Base flow represents a similar though slower movement and concentration of ground water.

A large literature on soil erosion and conservation is merely sampled in the papers cited in Section E, which call attention also to management and cultural factors. These flows of water and sediment represent transfers of a mass-budget surplus on upland slopes, and shape the receiving surfaces in various ways. The most common way is in the formation of flood plains, the economic properties of which are as interesting as their budget properties (Sections F and G). Flood plains occupy a curious blind spot in our land-management policies, as shown in references selected to suggest how many different ways there are of looking at a particular kind of terrain.

A. Characteristics of Mosaics that are Made up of Ecosystems, Plant Communities, or Slopes

1. Baumgartner, A. "Energetic bases for differential vaporization from forest and agricultural lands." In: Forest Hydrology, W. E. Sopper and H. W. Lull, eds., New York: Pergamon Press, 1967, 381-389. [Uses the energy budgets of different cover types to determine differences in their water requirements.]

2. Rauner, Yu. L. "The heat balance of forests and its role in the formation of the microclimate of wooded and treeless landscapes of the Moscow region." Soviet Geography 3, No. 6:40-47, 1962. [Different radiation characteristics of forest and fields, especially during presence of snow cover, and consequent differences in sensible-heat and latent-heat fluxes. Other studies from this productive research program of the Institute of Geography (not cited here) present seasonal regimes and water-budget effects of the forest-vs-field differences in energy budget, and some measure local energy transfers. See the geographical series of the A. N. Izvestiia.]

3. Lowry, W. P. "Energy budgets of several environments under sea-breeze advection in western Oregon." Journal of Meteorology 16: 299-311, 1959.

4. Idem. "Observations of atmospheric structure during summer in a coastal mountain basin in northwest Oregon." Journal of Applied Meteorology 2: 713-721, 1963. [Differences in slope orientation produce differences in heat budgets.]

5. MacNeish, R. S. "Ancient Mesoamerican civilization." Science 143: 531-537, 1964.

6. Idem. "The origin of New World civilization." Scientific American 211, No. 5: 29-37, May 1964. (Scientific American reprint 625) [Sequent occupance of microenvironments in the Tehuacán valley over several millenia, each agricultural exploitation using distinct combinations of water and nutrients.]

7. Flannery, K. V., Kirkby, A.V.T., Kirkby, M.J., Williams, A. W., Jr. "Farming systems and political growth in ancient Oaxaca." Science 158: 445-454, 1967. [The Oaxaca valley was dominant over several time periods because "virtually every farming technique known in Mesoamerica is applicable", utilizing different water conditions in each microenvironment. This paper was discussed in at least four courses on one campus in the same week it appeared, and has since proven useful even for elementary students of cultural geography.]

8. Lowenthal, D., and Prince, H. C. "The English landscape." Geographical Review 54:309-346, 1964. (Bobbs-Merrill reprint G-139) [The visible nature of landscape mosaics formed by combinations of trees and fields.]

9. Weaver, J. C. "Crop-combination regions in the Middle West." Geographical Review 44: 175-200, 1954. [Shows combinations of crops in each county; such combinations express local diversity in energy and water budgets.]

10. Ovington, J. D., Heitkamp, D., and Lawrence, D. B. "Plant biomass and productivity of prairie, savanna, oakwood and maize field ecosystems in central Minnesota." Ecology 44: 52-63, 1963. [Excellent comparison of production from different ecosystems in a typical midwestern mosaic of land uses. Differences in energy storage are also brought out.]

[Mosaic landscapes come about by a mixing of land uses (see references III F-2 and 3), an intermingling of lakes or bog with upland surfaces (III F-6), the growth of sheltering vegetation in strips or groves (VI E-5 to 7 and VII B-8 and 9), or the hydraulic dissection of the land into surfaces of diverse slopes and orientations (III C-15 and VI B-16). These differentiations in surface properties bring about a re-distribution of incoming energy and water and give rise to different plant communities or ecosystems and to local circulations (III A-8). Differences in albedo among elements of the mosaic are common, as seen in references III C-9 to 11, C-14, and III F-6. Differences in soil moisture also are common, influencing luxuriance and growth rates of vegetation. (Ref. III F-3 gives a desert-oasis contrast.)]

B. Local Movement of Energy and Moisture Among the Elements of a Mosaic Landscape

1. Rider, N. E., Philip, J. R., and Bradley, E. F. "The horizontal transport of heat and moisture—a micrometeorological study." Quarterly Journal of the Royal Meteorological Society 89:507-531, 1963.

2. Vries, D. A. de "The influence of irrigation on the energy balance and climate near the ground." Journal of Meteorology 16: 256-270. 1959. [A discontinuity between dry and wet surfaces causes changes in the radiation budget as well as in the fluxes of the energy budget.]

3. Miller, D. H. "Snow cover and climate in the Sierra Nevada, California." University of California Publications in Geography, 11, 1955. 218 pp. [Local advection of sensible heat from forest areas to snow cover in open meadows accelerates the rate of melting, produces high rates of melt-water stream flow, and accounts for an anomalously high level of air temperature. Relations between upper-air flow, pine stands, and snow cover are quantitatively worked out by means of the energy budget to explain why snow cover does not here produce a cold climate.]

4. Crawford, T. V. "Computing the heating requirements for frost protection." Journal of Applied Meteorology 3: 750-760, 1964. [The input of artificial-source energy required to prevent freezing depends on local advection of cold air from lands adjacent to the orchard, as well as on the deficit in the orchard's own radiation budget. Cf. orchard heating in Brooks's book, III A-6.]

5. Grable, A. R., Hanks, R. J., Willhite, F. M., and Haise, H. R. "Influence of fertilization and altitude on energy budgets for native meadows." Agronomy Journal 58: 234-237, 1966. [Water budgets of meadows at altitudes from 2200 m to 3100 m in Colorado differ, because different amounts of sensible-heat are advected from the surroundings of each.]

6. Dunbar, G. S. "Thermal belts in North Carolina." Geographical Review 56: 516-526, 1966. [Folk ideas about the inversion belts in mountain valleys, a consequence of local cold-air movement. Climate is as much a set of expectations as a set of physical relations, and needs more of this kind of field study.]

7. Alexander, R. R. "Minimizing windfall around clear cuttings in spruce-fir forests." Forest Science 10: 130-142, 1964. [Mosaics of clear-cut and forested land are subject to hazards of windfall.]

8. Aslyng, H. C. "Shelter and its effect on climate and water balance." Oikos 9: 282-310, 1958. [Danish experience with tree belts and other means of producing a mosaic landscape on terrain swept by winds off the North Sea. Cf. ref. I F-3 on wind power here.]

9. van Eimern, J., Karschon, R., Razumova, L. A., and Robertson, G. W. Windbreaks and Shelterbelts. World Meteorological Organization, Technical Note 59, 1964. 188 pp. [Authoritative, cross-cultural review of alterations in budgets of energy and water of areas of low vegetation in a mosaic of low and high growth forms.]

[Movement of sensible heat from warm absorbing surfaces in the landscape mosaic to such cold surfaces as moist foliage or snow is described in references III E-4, VI A-18 and VI B-5 and 7. See also item A-2 in this unit. Cross-reference may be made to items VI E-5 to 7, VI G-7, and VIII D-4 for other material on effects brought about by introduction of shelterbelts into the regional landscape.]

C. Local Advection of Substances Other Than Water Vapor

1. Van Arsdel, E. P. "Micrometeorology and plant disease epidemiology." Phytopathology 55: 945-950, 1965. [Atmospheric transport of spores, and conditions favorable to their survival.]

2. Hewson, E. W., et al. "Air pollution by ragweed pollen." Journal of the Air Pollution Control Association 17: 651-658, 1967. [Source — diffusion — receptor sequence.]

3. Janssen, C. R. "Recent pollen spectra from the deciduous and coniferous-deciduous forests of northeastern Minnesota: a study in pollen dispersal." Ecology 47: 804-825, 1966. [The pollen rain can be separated into the fractions from local sources, from adjacent slopes and uplands, and from region-wide sources—three scales of transport.]

4. Woodwell, G. M. "Toxic substances and ecological cycles." Scientific American 216, No. 3: 24-31, March 1967. [Paths of various poisons in food webs of ecosystems often have an aerial link.]

5. Calvert, S. "The ring around the air basins." Journal of the Air Pollution Control Association 17: 366-367, 1967. [Mapping an air basin as a "self-contained air pollution system of source—transport—receptor" under specified atmospheric conditions. Cf. reference II D-1?.]

6. Alexander, G. "Occurrence of grasshoppers as accidentals in the Rocky Mountains of northern Colorado." Ecology 45: 77-86, 1964. [Resulting from diurnal updrafts into mountains from adjacent "lowland source-habitats."]

[Aerial transport of dust (references I G-5 to 7), pollen and spores (II C-8 to 10), or biocides (II C-14) and pollutants (II C-12 and D-3 to 6) takes place among the elements of a mosaic of intermingled surface types. Diffusion phenomena are receiving study in urban settings; references in Unit II may be relevant to local transports in rural regions as well.]

D. Local Movement of Water at the Ground Surface and Its Collection into a Drainage Network

1. Hemming, C. F. "Vegetation arcs in Somaliland." Journal of Ecology 53: 57-67, 1965. [Patches of grass survive by receiving runoff from bare ground upslope from them.]

2. Slatyer, R. O. "Methodology of water balance study conducted on a desert woodland (Acacia aneura F. Muell) community in central Australia." Arid Zone Research 16: 15-26, 1961.
3. Idem. "Measurements of precipitation interception by an arid zone plant community (Acacia aneura F. Muell)." Ibid. 25: 181-192, 1965.
4. Turner, J. C. "Some energy and microclimate measurements in a natural arid zone plant community." Ibid. 25: 63-70, 1965. [Local movements of rain and surface runoff bring additional water from bare inter-grove bands to strips of woody vegetation, where infiltration is high. Grove and inter-grove areas also differ in radiation balance and soil temperature.]

5. LaChapelle, E. R. "The control of snow avalanches." Scientific American 214, No. 2: 92-101, February 1966. [Local movement of snow.]

6. U. S. Corps of Engineers. Snow Hydrology. Summary Report of the Snow Investigations. Portland, Oregon: Corps of Engineers, 1956;

reprinted by Government Printing Office. [Seven years of intensive field measurement of geologic, geomorphic, land-use, vegetation, meteorological, and microclimatic conditions of the environment of the snow cover in three mountain drainage basins in California, Oregon, and Montana, yielded an unusual body of data (published in hydrometeorological logs, which are available from the Corps), for application to problems of the heat and water budget of the snow. Results of Scandinavian heat-budget glaciology were modified, after research on quantitative geomorphology, terrain effects on snow accumulation, albedo, long-wave radiation, melting rates, and movement of melt-water, to obtain relations applicable to rugged, forested basins of the western United States. Working procedures were then developed for determining rates of snow melting and collection of melt runoff, for purposes of spillway design and reservoir operations on large basins. The program was interdisciplinary, and many geographers contributed, especially to the integrative aspects and the heat budgets. Excellent data for student problems.]

7. Rantz, S. E. Snowmelt Hydrology of a Sierra Nevada Stream. U. S. Geological Survey Water-supply Paper 1779-R, 1964. 36 pp. [Illustrates the energy-budget method of "Snow Hydrology" in calculating daily stream flow.]

8. Muller, R. A. "The effects of reforestation on water yield. A case study using energy and water balance models for the Allegheny Plateau, New York." Publications in Climatology 19, No. 3: 249-304, 1966. [Change in land use following failure of upland dairy farming resulted in change in water outflow, which is evaluated by three models, including the energy-budget model. This study exemplifies how a change in the cultural framework may be reflected in physical processes at the earth's surface.]

9. Eschner, A. R., and Satterlund, D. R. "Forest protection and streamflow from an Adirondack watershed." Water Resources Research 2: 765-783, 1966. [Recovery of forest cover after logging, fires, and insect attack was found to be associated with a decrease in stream flow. A storm in 1950 brought about a return to the 1912 state.]

10. Sopper, W. E., and Lull, H. W. "Streamflow characteristics of physiographic units in the Northeast." Water Resources Research 1: 115-124, 1965. [Yield, flow-duration relationships, and peak-flow frequencies in different terrains.]

11. Wong, S. T. "A multivariate statistical model for predicting mean annual flood in New England." Annals of the Association of American Geographers 53: 298-311, 1963. [A good example of a quantitative relation between terrain characteristics of drainage basins and their momentary export of water, worked out by a method superior to the once-ubiquitous multiple regression.]

12. Hidore, J. J. "Effects of glaciation on streamflow in the upper Mississippi Valley." Journal of Hydrology 3: 131-144, 1965. [Streams in glaciated country yield no more water and vary considerably more in flow than do those in the Driftless Area.]

13. Cline, D. R., with collaboration of M. W. Busby. Hydrology of Upper Black Earth Creek Basin, Wisconsin. U. S. Geological Survey Water-Supply Paper 1669-C, 1963. 27 pp. [Typical of recent studies of drainage basins, which combine data on surface- and ground-water outflow to give an integrated approach to an areal hydrology.]

14. Kennon, F. W. Hydrologic Effects of Small Reservoirs in Sandstone Creek Watershed, Beckham and Roger Mills Counties, Western Oklahoma. U. S. Geological Survey Water-Supply Paper 1839-C, 1966. 39 pp. [Unlooked-for effects of small flood-retarding reservoirs: a reduction in total flow; and seepage that made streams below the dams perennial, with consequent growth of riparian vegetation and change in channel shape and capacity.]

15. Cruickshank, A. B. "Water-resource development in the Campsies of Scotland." Geographical Review 55: 241-264, 1965. [Changing value of water surplus from a hill region, used first for local energy generation, later as process water, and then for export to cities.]

16. Williams, M. "The historical geography of an artificial drainage system: the Lower South East of South Australia." Australian Geographical Studies 2: 87-102, 1964. [Not all drainage networks are made by nature, but time seems to be a requisite.]

17. Dury, G. H. "Rivers in geographical teaching." Geography 48: 18-30, 1963. [Attempts to correct some common errors about rivers and stream flow.]

18. Pardé, M. Fleuves et Rivières, 4th edition. Paris: Librairie A. Colin, 1964. 224 pp. [Geographic treatment of rivers of the world, with special emphasis on floods. Useful comparative figures.]

19. Morton, F. I., and Rosenberg, H. B. "Hydrology of Lake Ontario." Transactions of the American Society of Civil Engineers 126, I: 795-822, 1961.

20. Sanderson, M. "A climatic water balance of the Lake Erie basin 1958-1963." Publications in Climatology 19: 1-87, 1966. [Budget studies for better management of the lakes. Cf. refs. VIII B-28 to 30.]

[Ground-water flow sometimes serves as a unifying agent in a local area; see items VIII B-31 to 33. Overland flow of water over slopes that were cut by and contribute to a typical drainage network is described at length in hydrology books, such as those referred to in Section IV A.]

E. Movement of Water-borne Solutes and Sediment

1. Feth, J. H. "Nitrogen compounds in natural water: a review." Water Resources Research 2: 41-58, 1966. [Nitrogen from the atmosphere and biosphere becomes concentrated in surface and ground water.]

2. Browning, G. M. "Agricultural pollution—sources and control." In: Water Pollution Control and Abatement, T. L. Willrich and N. W. Hines, eds. Iowa State University Press, 1967, 150-166. [Solutes, biocides, and sediment are among the off-site yields of crop and livestock enterprises in Iowa. Problems are anticipated.]

3. Strahler, A. N. "The nature of induced erosion and aggradation." In: Man's Role in Changing the Face of the Earth, W. L. Thomas, Jr., ed. University of Chicago Press, 1956, 621-638. [Generalizes empirical data on slope erosion and aggradation by use of geomorphological theory.]

4. Kedar, Y. "Water and soil from the desert: some ancient agricultural achievements in the central Negev." Geographical Journal 123: 179-188, 1957.

5. Evenari, M., et al. "Ancient agriculture in the Negev." Science 133: 979-996, 1961. [A stable agriculture that employed sophisticated hydrologic design in transporting and concentrating water and soil debris on selected sites, to provide soil moisture and nutrients for plant growth.]

6. Haggett, P. "Land use and sediment yield in an old plantation tract of the Serra do Mar, Brazil." Geographical Journal 127: 50-62, 1961.

   [A brief coffee-growing cycle about a century ago brought about the movement of some 20 centimeters of soil from slopes into colluvial deposits.]

7. American Geophysical Union. Symposium on Watershed Erosion and Sediment Yields. [Proceedings]. Transactions of the American Geophysical Union 38: 885-927, 1957. [Upland and channel aspects of the transport of sediment. See also ref. IV A-11.]

8. Wolman, M. G. and Schick, A. P. "Effect of construction on fluvial sediment, urban and suburban areas of Maryland." Water Resources Research 3: 451-464, 1967. [Suburbanization and erosion: land bared for construction of houses and roads (about 19 square kilometers at any one time) generates large amounts of sediment, with serious downstream effects. Sediment yield is about a ton for each person added to the area's population.]

9. Rahn, P. H. "Sheetfloods, streamfloods, and the formation of pediments." Annals of the Association of American Geographers 57: 593-604, 1967. [The question of collection of surface runoff into a network of channels.]

10. Landgren, N. E., et al., "Watershed protection through farm planning." Journal of Soil and Water Conservation 18: 3-7, 1963.
11. Ogrosky, H. O. "Effects of conservation on water yield." Ibid. 18: 11-13.
12. Brown, C. B. "Role of small watersheds in river basin planning." Ibid. 18: 14-18.
13. Lord, G. R. "A conservation authority and water management." Ibid. 18: 28-30. [Metropolitan Toronto]
14. Myers, L. E. "Water conservation: a research challenge." Ibid. 18: 31-34. [Papers in this issue discuss uplands as sources of water yield, floods, and sediment, and recommend various means of land treatment.]

15. Schwab, G. O., Frevert, R. K., Edminster, T. W., Barnes, K. K. Soil and Water Conservation Engineering, 2d edition. New York: Wiley, 1966. 683 pp. [Practices used in forming land, roughening it, altering its water budget, and reducing energy-transfer from wind and surface flow of water.]

16. Held, R. B. and Clawson, M. Soil Conservation in Perspective. Johns Hopkins Press, 1965. 344 pp. [It is not clear what success we have had in ameliorating the effects of energy expended by wind or surface runoff on soils bared for cultivation. Geographic distributions of various measures are shown.]

17. Costin, A. B. "Mountain land problems: South Island impressions and Australian comparisons." New Zealand Geographer 20: 60-73, 1964.
18. Idem. "Management opportunities in Australian high mountain catchments." In: Forest Hydrology, W. E. Sopper and H. W. Lull, editors, New York: Pergamon Press, 1967, 565-577. [High value of water yield from mountains, and associated problems of floods and sediment. Costin uses the water-budget framework to discuss effects of the fragile vegetation cover on hydrologic processes, and the consequences of damage to vegetation and soil by grazing, fire, and road building by a water-management organization.]

19. Leopold, L. P., Wolman, M. G., and Miller, J. P. Fluvial Processes in Geomorphology. San Francisco: Freeman, 1964. 522 pp. [Extremely valuable summary of the quantitative expression of water-associated forces that shape the land. Chapter 3 deals with the water budget and its variability, especially in relation to sediment transport.]

20. Curry, L. "Landscape as system." Geographical Review 54: 121-124, 1964. [Critique of recent studies on energy flows in geomorphic processes.]

21. Holzner, L., and Weaver, G. C. "Geographic evaluation of climatic and climato-genetic morphology." Annals of the Association of American Geographers 55: 592-602, 1965. [Problems in determining how "climate" as a bundle of variables acts on land form and landscape.]

22. Tuan, Yi-Fu. "New Mexican gullies: a critical review and some recent observations." Annals of the Association of American Geographers 56: 573-597, 1966. [Discusses two rival models to account for gullying in the epicycle of deposition and erosion of flood-plain deposits.]

23. Leopold, L. B. "Water and the Southwest." Landscape 10, No. 1: 27-31, Fall 1960. [Periods of differing attitudes to and use of water, including current efforts to manipulate vegetation of upland slopes in the belief (never well demonstrated) that downstream land owners will receive more water.]

24. Zakrzewska, B. "Trends and methods in land form geography." Annals of the Association of American Geographers 57: 128-165, 1967. [Includes review of effects of water surpluses on texture, roughness, and pattern of the earth's surface.]

25. Schumm, S. A. "Quaternary paleohydrology." In: The Quaternary of the United States, H. E. Wright, Jr., and D. G. Frey, editors. Princeton University Press, 1965, 783-794. [Water budgets and yields of water and sediment are estimated for times past. Attention is given to the effects of hydrologic variation on interfluves (drainage texture), terraces, and depositional areas.]

[Reference may be made to papers in Section VII F, to papers on the local movement of water-carried solutes (items II A-6 and II B-1 to 4), and especially of suspended sediment (items VI E-8 and IV A-1, 11, and 12). See Tuan (IV A-17) for early statements of this role of water.]

F. Flood Plains as Case Studies of the Water-Sediment Budget

1. Weinberger, M. L., and Ford, E. C. "Protecting watersheds—ways and whys." U. S. Department of Agriculture Yearbook 1958: 356-361. [Data on relations of upland to floodplain, e.g., the ratio of eroding upland to silted or swamped lowland is 13 to 1; the ratio of damage is 1 to 1.]

2. Hoyt, W. G., and Langbein, W. B. Floods. Princeton University Press, 1955. 469 pp. [Account of the hydrologic processes on upland slopes that result in a river again occupying its flood plain.]

3. Wolman, M. G., and Leopold, L. B. "River flood plains: some observations on their formation." U. S. Geological Survey Professional Paper 282-B: 87-109, 1957. [Geomorphic aspects of flood plains.]

4. Thorpe, E. W., and Tweedie, A. D. "The New South Wales floods of February, 1955." Australian Geographer 6: 3-13, 1956.

5. Robinson, K. W., and Burley, T. M. "Flood-plain farming on the Maitland Flats, Hunter Valley, N.S.W." Economic Geography 38: 234-250, 1962.

6. Burley, T. M. "Flood and drought in the Hunter Valley of New South Wales and their impact upon the agricultural community." Tijdschrift voor Economische en Sociale Geografie 56: 193-199, 1965
7. Starr, J. T. "River-basin planning in Australia." Geographical Review 54: 117-118, 1964.
[Floodplains as areas where both nutrients and water are concentrated appear especially striking when they are surrounded by infertile, drought-ridden hill country. Their dairy farms are, however, threatened by flooding and debris deposition, and another major income generator of the region, the port, is threatened by river sediment. Hydrologic research is therefore central in work of the Hunter Valley Research Foundation and the Commonwealth Scientific and Industrial Research Organization, which looks toward better use of land and water by guiding the flow of investment into the region.]
8. Wolman, M. G. "Aspects of flood problems." Geographical Review 53: 462-464, 1963.
9. White, G. F. "Strategic aspects of urban flood plain occupance." Transactions of the American Society of Civil Engineers 126, I: 63-75, 1961.
10. Idem. "Optional flood damage management: retrospect and prospect." In: Water Research, A. V. Kneese and S. C. Smith, editors. Johns Hopkins Press, 1966, 251-269. [Means, other than building dams, to reduce damage from transient surpluses in the upland water budget may at last be given consideration.]
11. White, G. F. Human Adjustment to Floods: A Geographical Approach to the Flood Problem in the United States. University of Chicago, Department of Geography, Research Papers, No. 29, 1942.
12. Murphy, F. C. Regulating Flood-Plain Development. Ibid., No. 56, 1958. 216 pp.
13. White, G. F., et al., Changes in Urban Occupance of Flood Plains in the United States. Ibid., No. 57, 1958. 256 pp.
14. Shaeffer, J. R. Flood Proofing: An Element in a Flood Damage Reduction Program. Ibid., No. 65, 1960. 190 pp.
15. White, G. F., et al., Papers on Flood Problems. Ibid., No. 70, 1961. 234 pp.
16. Burton, I. Types of Agricultural Occupance of Flood Plains in the United States. Ibid., No. 75, 1962. 167 pp.
17. Kates, R. W. Hazard and Choice Perception in Flood Plain Management. Ibid., No. 78, 1962. 157 pp.
18. White, G. F. Choice of Adjustment to Floods. Ibid., No. 93, 1964. 164 pp.
19. Kates, R. W. Industrial Flood Losses: Damage Estimation in the Lehigh Valley. Ibid., No. 98, 1965. 76 pp.
20. Sewell, W. R. D. Water Management and Floods in the Fraser River Basin. Ibid., No. 100, 1965. 163 pp. [A series of studies on flood plains as valuable, vulnerable pieces of land, subject to changes in water budgets of distant slopes. The physical and hydrologic problems of flood plains are being overshadowed by economic and cultural problems, including the question why people expose their property to damage, and what their alternative courses of action are.]

21. Krutilla, J. V. "An economic approach to coping with flood damage." Water Resources Research 2: 183-190, 1966. [Flood insurance of the right kind could serve as a "rationing device, eliminating economically unwarranted uses . . . while not prohibiting uses for which a flood plain location has merit."]

22. Burton, I. "Education in the human use of flood plains." Journal of Geography 60: 362-371, 1961. [Maps now becoming available on areas subject to floods may be useful in local-area studies and teaching. (Ninety flood maps are now [1967] available in the Hydrologic Atlas series of the U. S. Geological survey.)]

23. Alternatives in Water Management. Report of Committee on Water, G. F. White, Chairman, National Academy of Sciences – National Research Council, Publication 1408, 1966. 52 pp. [It is possible that flooding and other water problems have more than one answer. Alternatives that ought to be investigated in the light of changing social goals include alternatives in objectives, engineering, management, institutions, and in timing and location.]

24. Harris, D. R. "Recent plant invasions in the arid and semi-arid Southwest of the United States." Annals of the Association of American Geographers 56: 408-422, 1966. (Bobbs-Merrill reprint G-252) [Control of floods created a new ecological niche, promptly filled by tamarisk, which is now busily transpiring from 700,000 acres of flood plain.]

25. Stone, E. C., and Vasey, R. B. "Preservation of coast redwood on alluvial flats." Science 159: 157-161, 1968. [Redwood's competitors are suppressed by flooding and silt deposition, and the trees themselves are benefitted by input of nutrients from floods. This item is from a late issue of Science that is full of concern for "the intrusions man makes into the environment on which life depends" (D. Wolfle, "The only earth we have," Ibid., p. 155). It also contains a report on a unique flood plain – the Fort Hall Bottoms – threatened by dam construction (B. Nelson, "Expansion of Idaho reservoir: Indians, scientists on warpath," Ibid., pp. 173-176), and a report on a committee investigating ecological and other consequences of large-scale application of chemical defoliators.]

G. Flood Plains of an Earlier America

1. Denevan, W. M. The Aboriginal Cultural Geography of the Llanos de Mojos of Bolivia. University of California Press, Ibero-Americana, No. 48, 1966. 160 pp.
2. Parsons, J. J., and Bowen, W. A. "Ancient ridged fields of the San Jorge River floodplain, Colombia." Geographical Review 56: 317-343, 1966.

3. Parsons, J. J., and Denevan, W. M., "Pre-Columbian ridged fields." Scientific American 217, No. 1: 92-100, July 1967. [These three studies describe the remaking, on a gigantic scale, of flood-plains and seasonally flooded lowlands of South America into what apparently was a highly productive mosaic of land and water.]

4. Coe, M. D. "The chinampas of Mexico." Scientific American 211, No. 1: 90-98, July 1964. [Land reclamation through drainage, to give permanently productive crop lands. Problems of maintaining the water level and keeping out salty water.]

5. Gibson, C. The Aztecs under Spanish Rule: A History of the Indians of the Valley of Mexico, 1519-1810. Stanford University Press, 1964. 657 pp. [Includes an account of the centuries-long effort to drain water out of the Valley of Mexico.]

6. Fox, D. J. "Man-water relationships in metropolitan Mexico." Geographical Review 55: 523-545, 1965. [Both export and import of water have been long-term problems in the Valley's water budget. They existed with Tenochtitlan, and have worsened since, causing loss of agricultural land, subsidence of urban land, and great expenditure on public works for water supply, flood control, and drainage.]

Problems:

1. From air photos, have students study the kinds of mosaic landscapes that occur in nearby rural areas—a variety of crop fields; crops mixed with woodlots; fields and shelterbelts; dry and irrigated fields; slopes and interfluves; or intermingled land and lake surfaces. What is the general size of the component elements? What general contrasts do they display in dryness, temperature, albedo, and roughness?

2. Examine radiative energy flows with regard to the variation they exhibit in dissected terrain, according to Baumgartner (quoted in Ref. III A-8, page 243). Leave gaps in the budget for students to fill in, and ask them to calculate the deviations Baumgartner gives for each flux as a fraction of its mean value. Why is this deviation from place to place larger for direct short-wave radiation than for diffuse short-wave, or for long-wave?

3. Compare the desert and cotton fields studied by Aizenshtat (Ref. III F-3), with respect to radiation, other energy flows, water use, and microclimate. Plot the profiles of humidity and temperature of soil and air. Why does the cotton field have a bigger surplus of radiative energy than the bare desert? Why then does it have a lower temperature?

Desert and Oasis near Bukhara, midday in August
(cal cm^{-2} $hour^{-1}$) (Aizenshtat)

86	39	125
-22	-57	-79
64	-18	46

to heat the air	-36
evapotranspiration	0
to heat the soil	-10
	-46

Temperatures:	
150 cm	36°C
20 cm	38°
surface	53°
-5 cm	40°

BARE DESERT

86	38	124
-16	-41	-57
70	-3	67

to heat the air	-3
evapotranspiration	-60
to heat the soil	-4
	-67

Temperatures:	
150 cm	31°
20 cm	31°

-5 cm	35°

COTTON FIELD

4. Other comparisons of the energy budget of diverse, adjacent ecosystems or other surfaces are: forest and crops (ref. A-1), forest and snow-covered meadow (A-2 and B-3), forest and bare ground (D-4). These comparisons of abutting pieces of the earth's surface are quantitative, and show how different surfaces respond to similar inputs of energy. They illustrate one fundamental cause of geographic differentiation on a local scale that students can easily see.

5. Not only energy budget but also productivity of adjacent pieces of the earth's surface varies. Compare that of forest, prairie, and corn field in the midwest (A-10), and compute this in calories as a percentage of incoming solar radiation.

6. Convert data on the artificial input of energy to a citrus orchard on a cold night (ref. B-4) to calories per square centimeter, and also to gallons of fuel oil, and to kilowatts, as if electric heaters were to be used.

7. From Garnett's study of radiation differentiation in the upper Rhone valley (III C-15) and Yoshino's study of wind-force differentiation in the same place (I D-8), can you divide the valley into districts on a basis of their conditions of sun plus wind?

8. If you live in hilly country, have students describe, perhaps by making field measurements on a still night, the local inversions and cold-air pools. How do the people of the area perceive this recurrent phenomenon (ref. B-6)?

9. What are the relative rates of infiltration of water in forest and intergrove areas in the vegetation region studied by Slatyer (D-2 and 3), and how are they related to the overland flow of water? What are the effects on the vegetation in these two areas?

10. Plot through the year the values of monthly precipitation, change in water storage in snow mantle and soil, evapotranspiration, and runoff in the valley of Castle Creek in California (see pages 29-32 of ref. B-3; other information in D-6). Calculate how the water budget operates in a typical year, beginning with a dried-out basin at 1 October, accumulating water in storage during the winter, and discharging from storage in late spring.

11. In Muller's study of Allegheny water budgets (ref. D-8), compare the different methods by which he determined the water budget of small drainage basins, and hence the effect of afforestation of abandoned farm land.

12. From stream-flow data published by the U. S. Geological Survey in Water-Supply Papers, you can get summarized data for your local river. From these tables of daily flow, calculate the number of days of low flow below certain thresholds. At what seasons does it usually come? Are these the periods when there is likely to be a demand for water for supplementary irrigation of crops?

13. From Pardé's book (ref. D-18), graph the mean volumes of flow in major rivers of the world, along with the stream of comparable size nearest your city.

14. Compare yields of sediment from lands being urbanized around Baltimore (ref. E-8) with the amounts considered usual for erosion from midwestern and southern farm lands.

15. Work out a rough energy budget for a tamarisk flat on the Pecos River. Look up the solar radiation in a summer month, and assume that albedo is 0.15 and net loss of energy by long-wave radiation is -200 ly per day. If all the surplus in the radiation budget goes into evapotranspiration, how much water is vaporized per day? From 50,000 acres of tamarisk on the flats of this river (ref. F-21), how many acre-feet of water are consumed during the month? If downstream irrigable lands need 50 cm of water, how many acres are being deprived of water by the tamarisk?

16. As a class project, make a reconnaissance survey of a local flood plain—not too large. How is it delineated as a geographical feature? What is its flood history? Are floods from rain or snow-melting? From remote or nearby uplands? How deeply was it inundated at times in the past? What is the likely greatest depth of flooding? The survey should include land-use, circulation facilities, and position of the plain within the metropolitan complex—central or peripheral. Field-interviewing experience could be gained by the students if they investigated the question of how people who live on the plain or manage property there perceive their situation and degree of jeopardy. In what respect does their perception differ from that of hydrologic engineers (city or federal) who have surveyed the flood plain?

    A project of this kind could be small or, if desired, could become rather complex. The University of Chicago studies (F-11 to 20) provide excellent models for either a local survey or one going into questions and causes of land utilization. Where flood-plain maps (ref. F-22) of the Geological Survey's Hydrologic Atlas series exist, they should become the base map for the survey. These plains are geographic entities often distinguished by the intensity of the physical and cultural problems that meet on them; they embody many geographic ideas in a small space.

17. Students with historical or anthropological leanings might want to do a comparative analysis of water management in Mexico (refs. A-5 to 7 and G-4 to 6), South America (G-1 to 3), and Israel (E-4 and 5). Those with a bent toward economics or political science might want to see how we try to cope with the flooding behavior that all streams exhibit; references D-14, E-13 and 14, and in Section F present various alternatives.

UNIT VIII. SYNTHESIZING THE BUDGETS OF REGIONS INTO THE THE WORLD PATTERN

Objectives:

To illustrate that a region that is built up of many landscape mosaics has its own energy and mass budget, and that we can study regional inputs and outputs as bases for development programs;

To examine the factors responsible for connections and correlations among regional energy budgets, water budgets, and economies;

To express differences among regions quantitatively by use of budget fluxes and storages, and so to portray the global pattern.

Outline:

A. Regional budgets of energy and water

- Relative weights of local and external forces, especially in regions under steady or alternating advection
- Whole-region inputs and outputs
  - Inputs of radiative and advected energy, and water
  - Modifications in inputs, especially of water
  - Yields of bulk water, plant and animal tissues, energy
- Budgets for developing regions.

B. Interactions among factors producing the world pattern

- Endogeny, orographic barriers, and differentiation in substrate storage of energy and water
- Radiation patterns over the earth
- Atmospheric circulation (zonal or cellular?)
- The resultant global pattern of climatic budgets.

Commentary:

It comes easily to geographers to think of the currents of income and outgo to and from large sectors of the earth's surface—the nation's balance of payments, its imports and exports, a region's balance of trade, its need for development. The same analysis applies to flows of energy, water, or other forms of matter taking place on a regional scale. This scale is larger than that characterizing the mosaic landscapes of Unit VII. Regions at this scale form patterns on the globe, like the global patterns of economies, political units, or culture realms. In this unit we consider information and concepts that advance our knowledge of regions and of the world pattern they form, and employ the method of casting budget accounts of mass and energy at the surface of the earth.

For budgeting study, lands under strong advection of energy or moisture from other parts of the world form obvious entities, because they receive uniform inputs of energy and water from above. We begin, therefore, with regions that much of the time are dominated by air streams coming from other parts of the world. These streams bring with them the impress of their recent sojourns over surfaces at which the energy and water budgets were different than in the receiving region, which therefore experiences abrupt changes in its energy and water budget when invaded. Coastal lands, adjacent to an extensive surface with a radically different energy budget than the land, afford excellent examples of the influence of advection.

The donor regions (or source regions, in air-mass language) are less the object of interest than are the recipient regions, which feel the clash of prolonged or repeated invasions of air streams that contrast with local budget conditions. This alteration tends toward a more uniform value of the formerly heterogenous budgets and climates of the individual mosaic landscapes in the recipient region. Uniformity is imposed by an external force majeure. Thereby the recipient region, unified by a single outside force, stands on a level in the areal hierarchy higher than the mosaic landscapes of Unit VII.

Budgets of energy and especially of water can be cast on this regional scale, balancing region-wide inputs against region-wide outputs. For example, the inputs of water, salt, and sediment to the Iraq lowland are readily visualized, and have been put into budget form. Many such budgets have implications along biological, economic, and cultural lines, as well as physical and chemical. Problems of regional development sometimes involve modification in energy supply and almost always in water, more tractable than energy in man's hands. Irrigation methods and proposals figure in many of the case studies relevant to this scale.

Case studies of energy and mass budgets are made also for regions less touched by economic or cultural problems. The polar lands and the oceans are the best examples. Moreover, the extensive uniformity of their surfaces minimizes the difficulty of accurate sampling, and an international esprit among geophysicists has lavished scientific skills on these frontier regions—the Antarctic, the Arctic.

They provide good illustrations of the workings and joint action of the budgets. Their pedagogic value is enhanced by their uniformity, so that the ideas established in Unit VI about areal associations of energy and water transactions can be seen by students to carry directly into these much larger areas of the earth. Energy budgets at Amundsen-Scott Station, 90°S, or Eismitte, 71°N, clearly represent thousands of adjacent square kilometers of the Antarctic or Greenland ice plateaus. Budgets of water bodies, as given, for example, by Muromtsev's regionalization of the Pacific Ocean, are based on extensive measurements of surface temperature, the vital parameter that mediates the energy fluxes but which is scarcely known on the continents.

Oceanic surface budgets are significant not only for regional study, but also because they play an intermediary role between the vast storage of energy in the substrate and its rapid transports in the atmosphere. Feedbacks and interactions between ocean and atmosphere are now recognized as fundamental in long-range synoptic situations (periods of weeks and months), and in climatic variations (periods of years).

Changes in climate on the margins of the northeastern Atlantic Ocean have long been studied. In the work of Scandinavian geographers and geophysicists they occasioned the first systematic study of glaciological budgets; long series of climatic observations have been made in Europe; and the implications of a downturn from the favorable conditions of the past half-century, given the present energy requirements of agriculture, are serious to contemplate. These conditions combine to promote study of changes in regional climates, their relations to oceanic energy budgets, and their possible consequences in the economy.

Climatic changes are felt over large areas since they are associated with shifts in location of the principal components in the general circulation of the atmosphere. Discussing climatic change therefore leads the student into the general circulation, which is one of the approaches to the final topic of the course: the pattern of mass and energy budgets over the surface of the globe. This pattern expresses the working of three factors. One is the general circulation of the atmosphere, which exerts an advective control on the climate of a place; the second is the distribution of incoming solar radiation and the surplus of net whole-spectrum radiation; the third is energy storage in the ocean basins and the relief of the continents, the endogenous factor. The first and second controls, circulation and radiation, are not wholly independent of one another nor of the endogenous control.

The complex of these three interacting conditions presents itself as a formidable problem of interpretation, to which no cut-and-dried answer can be given. Rather than try to disguise the problem or retreat to the pointless numbers of a climatic classification, the teacher can show that the global pattern can be approached from several directions. (a) One of these is along the path suggested in this teaching unit: from regional budgets to oceanic budgets, to their effect on major features of the circulation, especially when it changes, and produces changes in regional climates. This leads to a fuller depiction of the general circulation than the simple wind belts seen by students in the early part of the course. It also is more complete than the depiction of the global pattern of rainfall in Unit IV, though both these prepared the way for the present analysis.

(b) A second approach flows from the world patterns of solar radiation and the surplus in the radiation budget, examined in Unit III. This pattern is not entirely latitudinal or zonal, because it is modified by clouds in ascending limbs of the atmospheric circulation and by effects of land and sea. Otherwise, we should find the most insolation in equatorial latitudes, which we do not. However, the pattern does display some zonal attributes, especially where unaffected by the great mountain chains of the globe.

(c) The third approach to the global climatic pattern takes into account the effects of continental relief and oceanic energy storage. These operate on the circulation, the radiation budget at the earth's surface, and the transformation of radiation in the energy budget. In Unit III the role of storage in the energy budget was seen in specific places, and it now can be generalized to continents and oceans and its role in identifying marine and continental influences made plain on a global scale.

Students should now be in a position to judge how each of these approaches functions by itself and then how it works in combination with the other two. In this way, they reach some interpretation of the world pattern as it results from this mixture of influences, and can see why the pattern exhibits both cellular and zonal attributes.

The linking of regional energy and water budgets into the global distribution in this unit may be treated in greater length than indicated. Many teachers will want to stress global patterns in their relation to those of agriculture, wildland vegetation, economy, and so on. Sufficient references are supplied for such an increased emphasis, which also can be supported by drawing case studies of particular parts of the earth from earlier units of the course. Some reviewers suggested such an increase in emphasis on global matters, but others suggested compressing all the synthesizing units in favor of the systematic ones of the first half of the course. The choice made by the teacher in this basic question might well depend on the availability of other courses, say on regional development, and on his own interests. Systematic study of the budgets of energy and matter and the subsequent examination of their areal syntheses in successively larger pieces should in any case provide a solid foundation for either a short or a long examination of their distributional patterns over the whole world.

References:

The first section of references cited in this teaching unit includes papers on regions dominated by strong invasion of air from other parts of the world, which by its uniform impact over a wide area unifies many mosaic landscapes into a larger whole. Some of these regions are coastal lands, where local differences among landscapes of the coastal lands are submerged by advection from a contrasting ocean surface. In other regions, such as the midwestern United States or the Paris Basin, advection is multiple-source rather than single, but no less dominating. Changes in advection are irregular and have to be kept under surveillance by forecasting organizations; a few references on implications of weather forecasting are cited. A more constant kind of advection is described by Chang and Lydolph. References from the desert locust program describe advection of biological organisms, now rare in the United States but important in many other places.

Section B contains references to regions as large as those dominated by advection, but unified in less obvious ways. In these case studies the unifying theme may be a phenomenon, such as soil moisture on the Great Plains, that is a resultant of local mass and energy budgets. Implications of regional problems and regional development are found in many references.

Lack of data prevents a world-wide coverage of regional budgets, but enough are available for systematic examination of widely separated parts of the earth. Some references have been grouped so as to pool data on budget components and their connections with life and economy. For example, items B-16 to 21 on deserts, and B-28 to 30 on the Great Lakes, reinforce each other. Three papers report budgets of water, solutes, and sediment for Iraq, a region lending itself well to the budget approach. Papers B-1 to 6 show how the soil-moisture probabilities developed by Curry for the Waikato Valley in New Zealand bring out the essence of seasonality, are associated with biological productivity that can be compared with that of other dairying regions, and can be examined as the base for land management and settlement. The Waikato papers make a neat package on implications growing out of the regional energy and water budgets. An instructor who is so inclined might pursue these implications on to the national level, and consider New Zealand's place in the world economy at this present critical point in its history.

Budget concepts are being applied to problems of regional investment in the economies of the United States (references of Section C) and the Soviet Union (Section D). In the United States, many regions that have run through cheap local water are beginning to think about inducing the nation to bring them more. This is a political question that starts with the water budget, and which has, in recent years, become merged with the still larger problem of restoring the American environment, making cities and countryside, water bodies and atmosphere, into more workable and livable surroundings.

In the Soviet Union, water-budget problems sometimes draw in the energy budget. Regional development usually means consciously to transform the heat-and-water budget by means of irrigation, shelterbelt networks, swamp drainage, new cultivation practices, and other works. It includes efforts to take advantage of and enhance the seasonal and geographic distributions of such budget quantities as soil moisture, radiation surplus, and evapotranspiration regimes. A proposal such as to build large reservoirs for diverting water into the Volga Basin is regarded not merely as a matter of engineering the water-storage and conveyance structures, but also as a modification of nature with energy-budget and ecological connotations that might force changes in the final design.

Explicit formulations of mass and energy budgets have been made for ice plateaus and oceans. Budgets for Antarctica, whose existence results from a mass budget that piles up a surplus year after year, because the energy budget functions at a low level, have been worked out in detail in the years during and after the I.G.Y. Comparable studies are being published for the Arctic (Section E). Budgets of the oceans have been studied for years, and a rapprochement between meteorology and oceanography has recently intensified the attention to them (Section F). Budgets at the air-sea interface mediate between oceanic energy storage and the atmospheric energy budgets, which affects the atmosphere motion systems.

Section G includes papers on large-scale changes in climate. This is a reviving subject of inquiry, in which energy-budget exchanges at the air-sea interface delineate the role of oceanic storage in buffering or prolonging atmospheric fluctuations. Implications for agriculture of changes in climate are being examined in England and elsewhere, and consideration is also being given to the consequences, anticipated or inadvertent or merely stupid, of our own attempts to see if we can change the climate. The cautions expressed by Sargent and Whittaker about ill-considered or premature experimentation on other people's weather warrant any student's attention.

Oceanic budgets and large-scale atmospheric circulations, studied in relation with changes in climate, lead into the subject of the references in Section H, which is the global circulation itself and its role in the world pattern of climatic budgets. Transportation of water and energy in the general circulation is one of the principal factors in the world pattern of climate, along with the differences between oceans and continents in respect to albedo, relief, and energy storage, and the modified belts of radiation around the globe. The interpretation of the composite pattern of energy and mass budgets over the entire surface of the earth is thus in part zonal, or exogenous, arising from its location relative to the sun, and in part cellular, or endogenous, arising out of the convection within the earth that produces the pattern of continents and ocean basins. Papers cited in this final section set forth different ideas and points of view that should help the students interpret the complex global pattern of surface budgets.

A. Lands under Advection

1. Edinger, J. G. "Modification of the marine layer over coastal Southern California." Journal of Applied Meteorology 2: 706-712, 1963.
2. Byers, H. R. "Summer sea fogs of the central California coast." University of California Publications in Geography 3, No. 5: 291-338, 1930.
3. Patton, C. P. "Climatology of summer fogs in the San Francisco Bay area." Ibid., 10, No. 3: 113-200, 1956. [Advection of influences from outside the local region is illustrated along the Pacific coast, where surfaces of radically different heat budgets adjoin one another. See also a Record item in the Geographical Review 47: 591-594, 1957, and Leighly's classic study, III F-4.]

4. Leighly, J. B. "Profiles of air temperature normal to coast lines." Annals of the Association of American Geographers 37: 75-85, 1947. [Changes in heat budget in advected air, and resulting daytime and nighttime air temperatures. Cf. refs. III F-4 and 5.]

5. Davis, R. B. "Spruce-fir forests of the coast of Maine." Ecological Monographs 36: 79-94, 1966. [Cold advection from the ocean in summer, mapped from wind and sea-surface temperature data, is related to prevalance of this boreal type of forest.]

6. Williams, G. C. "An occurrence of lake snow. One of the direct effects of Lake Michigan on the climate of the Chicago area." Monthly Weather Review 91: 465-467, 1963.
7. Muller, R. A. "Snowbelts of the Great Lakes." Weatherwise 19: 248-255, 1966. [Advection of moisture and energy from the wintertime lakes produces areas of heavy snowfall downwind of each.]

8. Gutman, G. J., and Sch 'rdtfeger, W. "The role of latent and sensible heat for the development of a high pressure system over the subtropical Andes, in the summer." Meteorologische Rundschau 18: 69-75, 1965. [An excellent example of a regional energy budget, in which is included advection of cold air from the Pacific and latent heat from the Amazon basin.]

9. Sanderson, S. E. "Recipe for a course in weather communications: Hawaiian style." Bulletin of the American Meteorological Society 47: 800-803, 1966.
10. Shak, G. L., Scarpa, M., and Knudsen, C. G. "Temperature terminology for public forecasts." Weatherwise 19: 161-163, 1966.
11. McQuigg, J. D., and Thompson, R. G. "Economic value of improved methods of translating weather information into operational terms." Monthly Weather Review 94: 83-87, 1966. [Three papers on how to convey information on advective changes, specifically, forecasts of air temperature, to diverse groups of potential clients,

who may or may not have a workable relation between weather and a loss function in their operation.]

12. Chang, J.-H. "The Indian summer monsoon." Geographical Review 57: 373-396, 1967.
13. Lydolph, P. E. "A comparative analysis of the dry western littorals." Annals of the Association of American Geographers 47: 213-230, 1957. [Large-scale advection—of moist air in the summer monsoon, of dry stable air in the anticyclones of the eastern subtropical oceans is illustrated in these papers.]

14. Rainey, R. C. Meteorology and the Migration of Desert Locusts. World Meteorological Organization Technical Note 54, 1963. 117 pp.
15. World Meteorological Organization—Food and Agriculture Organization. Meteorology and the Desert Locust. Ibid., Technical Note 69, 1965. 310 pp. [Insects seldom are obvious as fellow-travellers in atmospheric advection, but these invasions cover several thousand square kilometers and consume vegetation at the rate of 10^8 kg per day. They move more or less in the direction of air flow, but more slowly.]

16. Pédelaborde, P. Le Climat du Bassin Parisien. Essai d'une Méthode rationelle de Climatologie physique. Paris: Librairie de Médicis, 1957. [Perhaps the most complete example of a synoptic climatography of a region experiencing advection from many, often remote, sources. Text and atlas volumes.]

[Sea-breeze advection is discussed in references in Sec. I D, III F, and VII A. The effects of advection of energy from storage in water bodies have been mapped by Leighly (refs. III F-4 and 5). Regional-scale advection figures in general works on the atmosphere (refs. I A-1 to 5), and in "Storm" (I C-1), and in descriptions of energy importation to the ice plateaus (III E-5 and VIII E-1 to 4). Moisture transports are used in various ways to regionalize precipitation regimes (IV E-18 to 21 and I A-5).]

B. Some Regional Case Studies Illustrating Budget Principles

1. Curry, L. "The climatic resources of intensive grassland farming: The Waikato, New Zealand." Geographical Review 52: 174-194, 1962.
2. Idem. "Regional variation in the seasonal programming of livestock farms in New Zealand." Economic Geography 39: 95-118, 1963. (Bobbs-Merrill reprint G-46.) ["Climate is not a fact but a theory, and it behooves each investigator to provide an ordering of the weather experience appropriate to this own purpose." In these studies the data are ordered so as to give expectancies of soil moisture, as a product of the energy and water budgets. These probabilities determine the timing of livestock operations and the storage of feed from one period to another.]

3. Lewthwaite, G. R. "Wisconsin and the Waikato: a comparison of dairy farming in the United States and New Zealand." Annals of the Association of American Geographers 54: 59-87, 1964. [Seasonality

in output is larger in the region that has the smaller seasonality in its energy budget. This paper presents a useful association of climatic and technological factors in two regional economies.]

4. Maunder, W. J. "Climatic variations and agricultural production in New Zealand." New Zealand Geographer 22: 55-69, 1966.
5. Idem. "Effect of significant climatic factors on agricultural production and incomes. A New Zealand example." Monthly Weather Review 96: 39-46, 1968. [Effects of one standard deviation from mean rainfall and sunshine in Waikato County can be expressed in terms of money income.]

6. Farrell, B. H. "Geography of power resources in the Waikato region." New Zealand Geographer 12: 133-154, 1956; Whitelaw, J. S., "The measurement of urban influence in the Waikato," Ibid. 18: 72-92, 1962: Blechynden, K., "An economic base analysis of Hamilton, 1961," Ibid., 20: 122-137, 1964. [These papers supplement those cited above on climate and primary production, and help students round out their geographic picture of the Waikato region.]

7. Hare, F. K. "Climatic and zonal divisions of the boreal forest formations in eastern Canada." Geographical Review 40: 615-635, 1950. [Includes heat-balance considerations.]

8. Olson, R. V., coordinator, "Agronomic trends and problems in the Great Plains." Advances in Agronomy 10: 1-66, 1958. [One of several descriptive regional agronomies. Regional practices in conserving and enhancing soil moisture are discussed, along with recent difficulties.]

9. Hewes, L. "Causes of wheat failure in the dry farming region, central Great Plains, 1939–1957." Economic Geography 41: 313-330, 1965. [Regional study of the effects of low soil moisture, as well as wind and other sources of damage.]

10. Saarinen, T. F. Perception of the Drought Hazard on the Great Plains. University of Chicago, Department of Geography, Research Paper No. 106, 1966. 183 pp. [How do farmers perceive the drought hazard, and why do some habitually underrate it?]

11. Brown, R. H. Historical Geography of the United States. New York: Harcourt, Brace, 1948. 596 pp. [See pp. 374-5.]
12. Lewis, C. M. "William Gilpin and the concept of the Great Plains region." Annals of the Association of American Geographers 56: 33-51, 1966. [Both authors present contemporaneous ideas about the Plains climate, including the supposed benefits of concentration of rain in the growing season.]

13. Cressey, G. B. "Water in the desert." Annals of the Association of American Geographers 47: 105-124, 1957. [A presidential address]
14. Al-Kashab, W. H. The Water Budget of the Tigris and Euphrates Basin. University of Chicago, Department of Geography, Research Paper No. 54, 1958. 105 pp.

15. Jacobsen, T., and Adams, R. M. "Salt and silt in ancient Mesopotamian agriculture." Science 128: 1251-1258, 1958. (Bobbs-Merrill reprint G-105) [Budgets of water and of dissolved and suspended matter, which have created and afflicted the land of Iraq.]

16. Allison, L. E. "Salinity in relation to irrigation." Advances in Agronomy 16: 139-180, 1964. [Review of problems where salt is imported along with water, and its effects on soils and crops. (Other sources of salt cited in items II A-3 to 6).]

17. Lewis, R. A. "Early irrigation in west Turkestan." Annals of the Association of American Geographers 56: 467-491, 1966. [Changes in techniques as scale increased in each center.]

18. Wiens, H. J. "Regional and seasonal water supply in the Tarim Basin and its relation to cultivated land potentials." Annals of the Association of American Geographers 57: 350-366, 1967. [Same old problems of expanded irrigation: evaporation, salting, swamping, brought on by over-enthusiastic engineers—these being Chinese.]

19. Loehnberg, A. "Water supply and drainage in semi-arid countries." Transactions of the American Geophysical Union 38: 501-510, 1957. [A lucid rationale for scheduling the development of water in basin-and-range country.]

20. Amiran, D. H. K. "Arid zone development: a reappraisal under modern technological conditions." Economic Geography 41: 189-210, 1965. [Different forms of settlement are recommended for arid than for semi-arid regions.]

21. Highsmith, R. M., Jr. "Irrigated lands of the world." Geographical Review 55: 382-389, 1965. [Map and discussion of data sources.]

22. Schaaf, C. H. and Fifield, R. H. The Lower Mekong: Challenge to Cooperation in Southeast Asia. Princeton: Van Nostrand, 1963. 136 pp. (Searchlight Book).

23. White, G. F. "Contributions of geographical analysis to river basin development." Geographical Journal 129: 412-432, 1963. [Development of a river basin calls for resource inventories (including a water budget) and choice of strategies and technologies, i.e., "a systems analysis of the whole complex of natural and social processes at work. . ." (White). See also White, "The Mekong River plan," Scientific American 208, No. 4: 49-59, April 1963.]

24. Sinclair, R. "Austria's place in Europe's electric-power exchange." Geographical Review 54: 93-103, 1964. [An energy export (about 10^{15} calories per year) deriving from atmospheric import of water vapor to a mountainous region.]

25. Carter, D. B. "The average water balance of the Delaware Basin." Publications in Climatology 11, No. 3: 245-269, 1958. [Regional-scale water budget. May be used in conjunction with later studies

on water demand and pollution in this important drainage basin, such as reference II E-10 and to New York's water, p. 16.]

26. Tomlinson, G. E. "In the Southeast river basins: land and water resources development plan." Journal of Soil and Water Conservation 18: 109-113, 1963. [Summarizes a comprehensive series of reports on water in the southeastern United States.]

27. Maass, A., Hufschmidt, M. M., Dorfman, R., Thomas, H. A., Jr., Marglin, S. A., Fair, G. M. Design of Water-Resource Systems. Harvard University Press, 1962. 620 pp. [From the Harvard water program. The problem is how to combine reservoirs and other facilities to produce an optimal seasonal distribution of water and energy yields.]

28. Pincus, H. J., editor. Great Lakes Basin. Washington: American Association for the Advancement of Science, Publication 71, 1962. 308 pp. [Includes work on a water budget that is based on the energy budget; both budgets are yet too little known to allow efficient management of the lakes. Cf. refs. VIII A-6 and 7.]

29. Powers, C. F., and Robertson, A. "The aging Great Lakes." Scientific American 215, No. 5: 94-104, Nov. 1966. (Scientific American reprint 1056).

30. Beeton, A. M. "Eutrophication of the St. Lawrence Great Lakes." Limnology and Oceanography 10: 240-254, 1965. [Too much contribution from tributary lands of such mass-budget items as organic and inorganic nutrients.]

31. Eakin, T. E. "A regional interbasin groundwater system in the White River area, southeastern Nevada." Water Resources Research 2: 251-271, 1966. [A region integrated by ground-water movement.]

32. Huff, F. A., and Changnon, S. A., Jr. "Relation between precipitation deficiency and low streamflow. Journal of Geophysical Research 69: 605-613, 1964. [A geomorphic index plus frequency distribution of precipitation gives frequency of low flows.]

33. Weeks, E. P., Ericsson, D. W., and Holt, C. L. R., Jr. Hydrology of the Little Plover River Basin, Portage County, Wisconsin, and the Effects of Water Resource Development. U. S. Geological Survey Wat. .-Supply Paper 1811, 1965. 78 pp. [Conflict over water to irrigate potatoes or as a habitat for trout resulted in a study on the relations between stream flow and ground water in this outwash plain. One unified water system was found, ground water being associated both with the water budget at the earth's surface and with flow in the streams. A film of this field investigation always seems to fascinate students.]

34. Thomas, H. E. and Leopold, L. B. "Ground water in North America." Science 143: 1001-1006, 1964. (Bobbs-Merrill reprint G-225) [Fields for research on ground water are aspects of "the overall objective of defining numerically the hydrologic system, and then analyzing regional flow patterns and superimposed chemical systems."]

[The group of papers on the New Zealand dairying valley can be used in contrast with those by Aslyng, et al., on Danish grassland budgets (refs. VI B-1, 2, and 3). For other regional studies of the Great Plains, see ref. I D-4, G-5 and IV E-17, and of the Great Lakes VII D-19 and 20 on budgets and VIII A-6 and 7 on lake-effect snowstorms. For other desert budget studies, see references VII E-4 and 5 on water and sediment management, and V E-1 to 7 on desert animals.]

C. National Problems of the Water Budget in the United States

1. Piper, A. M. Has the United States Enough Water? U. S. Geological Survey Water-Supply Paper 1797, 1965. 27 pp. [A long-range view of the supply of water and the possibilities of regulating it. The regulated supply is compared with likely changes in net commitment of water in the next 35 years, to meet changes in on-site uses (due to land treatment), off-channel consumption (by cities and irrigation), and in-channel flow (to provide for waste dilution, navigation, recreation, and fish habitat).]

2. Löf, G. O. G., and Hardison, C. H. "Storage requirements for water in the United States." Water Resources Research 2: 323-354, 1966. [What storage is required to meet commitments for water at the season they occur? Where will the new reservoirs be built? How much water will they waste through evaporation? Cf. Sec. VII F.]

3. U. S. Senate. Select Committee on National Water Resources. Committee prints. U. S. Congress, 86th, 2d Session. 32 prints in 3 volumes. Washington: U. S. Government Printing Office, 1959-1961. [A source for information on status and prospects. The Kerr Committee Report.]

4. White, G. F. "Industrial water use: a review." Geographical Review 50: 412-430, 1960. (Bobbs-Merrill reprint G-252) [Quantity of water now being used and estimated for the future; types of use, quality and sources of water, and elements involved in decisions about it.]

5. Ackerman, E. A., and Löf, G. O. G. Technology in American Water Development. Johns Hopkins Press, 1959. 709 pp. [A well organized series of studies arranged by function, e.g., technical events that can decrease the demand for water, events that promote economies of scale, and so on. Many case studies.]

6. Smith, S. C., and Castle, E. N. Economics and Public Policy in Water Resource Development. Iowa State University Press, 1964. 463 pp. [Essays on how to allocate funds for modifying the water budget. In these decisions "the economist is system-oriented;" he "thinks of nature as a factor of production to be treated gently in a cooperative manner ...." - K. Boulding, p. 82]

7. League of Women Voters. Education Fund. The Big Water Fight. Brattleboro, Vt.: Stephen Greene Press, 1966. 246 pp. [Local water problems involve local citizens, and this well-written book discusses problems of water supply, pollution, floods, and getting

plans that will provide for all contemplated uses of water. Parts deal with strategy and tactics. Case studies include the Sudbury-Assabet-Concord basin, in the path of Boston's suburbia.]

8. Wolman, A. Water Resources. A Report to the Committee on Natural Resources. National Academy of Sciences–National Research Council Publication 1000-B, 1962. 35 pp.
9. Nace, R. L. "Perspective in water plans and projects." Bulletin of the American Meteorological Society 47: 850-856, 1966. [What technology can and cannot do.]

10. Busby, M. W. Annual runoff in the conterminous United States. U. S. Geological Survey Hydrologic Atlas HA-212, 1966. 1 sheet.
11. McGuinness, C. L. Generalized map showing annual runoff and productive aquifers in the conterminous United States. Ibid., HA-194, 1964. 1 sheet.
12. Blakey, J. F. Temperature of surface waters in the conterminous United States. Ibid., HA-235, 1966. 3 sheets.
13. Rainwater, F. H. Stream composition of the conterminous United States. Ibid., HA-61, 1962. 3 sheets. [Geographic distributions of the off-site yield of water and the heat, solutes, and sediment that it transports are mapped in these hydrologic atlases.]

14. Macinko, G. "The Columbia Basin project: Expectations, realizations, implications." Geographical Review 53: 185-199, 1963. [A large, subsidized irrigation project is in trouble in its first decade of operation.]

15. Tinney, E. R. "Criteria for analysis of interregional transfers of water." Journal of the American Water Works Association 58: 1369-1373, 1966. [The best solution to a regional water problem is not necessarily to take it from another region.]

16. Thomas, H. E. "Water problems." Water Resources Research 1: 435-445, 1965. [Constraints on development: physical, technological, cultural, and economic.]

[Water in the United States is the subject of several papers cited in other units of this outline. See, for example, references on vapor transport (in Sec. IV D), storm rainfall (IV E), soil moisture and drought (IV F-13), yield from uplands with changing regional hydrologies (VII D), yields of sediment and pollution (VII E) and of flood flows with their consequences (VII F). The dangers of pollution and attempts to modify rain-bearing systems that are only poorly understood tie in with general problems of waste management (II E-10) and threats to the environment (II D-6, V A-9, and VIII G-12) that face this country. The idea of a "quick fix" for water problems should be dropped and we should consider alternatives of all kinds—technological and institutional; ref. VII F-23.]

D. Some Soviet Budgets

1. Popov, V. P., et al. "The study of the heat and moisture balance of the Ukraine as a basis for measures to raise the productivity of agriculture." Soviet Geography 2, No. 7: 16-27, 1961.

2. Vernander, N. B., et al. "Physical-geographic processes unfavorable for agriculture and control measures against them." Soviet Geography 5, No. 7: 1-67, 1964. [Includes droughts, sukhovey, dust, water-logging.]

3. Konstantinov, A. R. and Goisa, N. I., editors. Atlas Sostavliaiushchikh Teplovogo i Vodnogo Balansa Ukrainy. (Kiev: Ukrainskii Nauchno-Issledovatel'skii Gidrometeorologicheskii Institut.) Leningrad: Gidrometeorologischeskoe Izdatel'stvo, 1966. 170 pp. [Atlas of Components of the Heat and Water Balance of the Ukraine. With 151 maps, monthly, at critical seasons or over growth-periods of wheat and corn. Solar radiation, albedo, net surplus of whole-spectrum radiation, latent-heat flux, sensible-heat flux, soil-heat flux, precipitation, evapotranspiration and runoff.]

4. Davitaya, F. F. "Transformation of nature in the steppes and deserts." In: Soviet Geography, Accomplishments and Tasks. New York: American Geographical Society Occasional Publication No. 1, 1962, 281-289. [A review of soil moisture, and the energy budget of irrigated and unirrigated land; ameliorative work, including snow control and shelterbelts. This volume also discusses systematic fields of geography, including those associated with budget concepts (Chapters 9-15), and such interdisciplinary areas as the budget itself, snow cover, zonality, and landscape science (Chapters 21-26).]

5. Lydolph, P. E. "The Russian sukhovey." Annals of the Association of American Geographers 54: 291-309, 1964. (Bobbs-Merrill reprint G-143) [Damage to crops from descent of hot dry air from the free atmosphere along with other abnormal supplies of heat.]

6. Grigoryev, A. A. "The reclamation of the forest belt of the U.S.S.R. in Europe." Geographical Journal 119: 411-419, 1953. [Too little in the energy budget, too much in the water budget.]

7. Taskin, G. A. "The falling level of the Caspian Sea in relation to Soviet economy." Geographical Review 44: 508-527, 1954.

8. Vendrov, S. L. "Geographical aspects of the problem of diverting part of the flow of the Pechora and Vychegda Rivers to the Volga basin." Soviet Geography 4, No. 6: 29-41, 1963.

9. Vendrov, S. L., et al. "The problem of transformation and utilization of the water resources of the Volga River and the Caspian Sea." Soviet Geography 5, No. 7: 23-34, 1964. [Attempts to reconcile the water budgets of agricultural land and the Caspian are complicated by the needs of fisheries, power, and industry for water. Reservoirs of the project may also have unfavorable effects on their surroundings.]

10. Borisov, A. A. Climates of the U.S.S.R. Translated by R. A. Ledward. Chicago: Aldine [1965]. 255 pp. [Climate-forming factors: the radiation budget, circulation, and moisture budget, begin the discussion. Budgets are often employed in Soviet climatographies to set the physical framework.]

11. Atlas Sel'skogo KHoziaistva S S S R. Moscow: Glavnoe Upravlenie Geodezii i Kartografii, 1960. 308 pp. [Agricultural atlas, with maps on solar radiation, soil moisture and snow cover, etc.]

12. Lydolph, P. E. "Schemes for the amelioration of soil and climate in the U S S R." In: Soviet Agriculture and Peasant Affairs, R. D. Laird, editor. University of Kansas Press, 1963, pp. 204-212. [Heat and water budgets are guides to improving agriculture.]

E. The Polar Regions: Energy and Mass Budgets

1. Rusin, N. P. The Meteorological and Radiational Regime of Antarctica. Jerusalem: Israel Program of Scientific Translations, 1964. 355 pp.
2. Rubin, M. J., and Weyant, W. S. "Mass and heat budget of the Antarctic atmosphere." Monthly Weather Review 91: 487-493, 1963.
3. Rubin, M. J. "Antarctic weather and climate." In: Research in Geophysics, Volume 2, H. Odishaw, editor. Massachusetts Institute of Technology Press, 1964, 461-478.
4. Haurwitz, B. "Harry Wexler memorial lecture: Antarctic exploration." Bulletin of the American Meteorological Society 47: 258-274, 1966. [Mass and energy budgets have been central in Antarctic research, because of interest in whether the continent is shrinking or growing, as well as other geophysical questions. Energy budgets of the Antarctic atmosphere are often included in these studies, which perhaps give us a more complete picture of this continent than any other.]

5. Vowinckel, E., and Orvig, S. "Energy balance of the Arctic. I. Incoming and absorbed solar radiation at the ground in the Arctic." Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie B, 13: 352-377, 1964. "II. Long wave radiation and total radiation balance at the surface in the Arctic." Ibid., 13: 451-479, 1965. "III. Radiation balance of the troposphere and of the earth-atmosphere system in the Arctic." Ibid., 13: 480-502, 1965.
6. Vowinckel, E., and Taylor, B. "Energy balance of the Arctic. IV. Evaporation and sensible heat flux over the Arctic Ocean." Ibid., 14: 36-52, 1966. [A complete regional energy budget, including the earth's surface itself and the adjacent region in the troposphere.]

7. Donn, W. L., and Ewing, M. "A theory of ice ages III." Science 152: 1706-1712, 1966. [Energy budgets of an open and an ice-covered polar sea, and some consequences relevant to the sea as a source of moisture.]

[For other studies of the great ice plateaus, see references III E-5 and VI B-8, 9, and 10. Cf. references III F-8 and 9 on the Arctic budget.]

F. Ocean Budgets

1. Pickard, G. L. Descriptive Physical Oceanography. New York: Pergamon Press, 1963.
2. Muromtsev, A. M. Hydrological Features of the Pacific Ocean. Jerusalem: Israel Program for Scientific Translations, 1963. 417 pp. [Both books present the energy budget. Muromtsev uses it in discussing the regional distribution of water types.]

3. Carter, D. B. "The water balance of the Mediterranean and Black Seas." Centerton, N.J.: Laboratory of Climatology, Publications in Climatology 9, No. 3: 123-174, 1956. [Budgets of the seas and tributary lands.]

4. Colón, J. A. "Seasonal variation in heat flux from the sea surface to the atmosphere over the Caribbean Sea." Journal of Geophysical Research 68: 1421-1430, 1963. [Role of energy storage in the substrate is important, and delays peaks of some of the heat fluxes several months.]

5. Hastenrath, S. L. "On general circulation and energy budget in the area of the Central American seas." Journal of Atmospheric Sciences 23: 694-711, 1966. [Seasonal changes in import and export of latent and sensible heat.]

6. Benton, G. S., et al. "Interaction between the atmosphere and the oceans." Bulletin of the American Meteorological Society 44: 4-17, 1963. [Influence of the substrate on the pattern of world climates is complicated, and requires study of the exchange processes at the sea-air interface.]

7. Bjerknes, J. "Atlantic air-sea interaction." Advances in Geophysics 10: 1-82, 1964. [The energy budget of the sea surface varies from year to year, in relation with changes in the strength of the westerlies.]

8. Kraus, E. B. "Local interactions between the sea and the air at monthly and annual time scales." Quarterly Journal of the Royal Meteorological Society 92: 114-127, 1966. [Energy budgets calculated from observations at nine weather ships on the North Atlantic.]

9. Dickson, R. R. "The weather and circulation of December 1965 including a discussion of the record dry year in the Northeast." Monthly Weather Review 94: 192-197, 1966.
10. Namias, J. "Nature and possible causes of the northeastern United States drought during 1962-65." Ibid., 94: 543-554, 1966. [The drought was related to an anomaly in the upper-air pattern that might in turn have been related to an anomaly in sea-surface temperature. "Abnormalities of sea-surface temperature are created by anomalous surface wind drag and by extraction of heat by anomalous air masses." (Namias) See also idem, "Short-period climate fluctuations." Science 147: 696-706, 1965.]

11. van Loon, H. "On the annual temperature range over the southern oceans." Geographical Review 56: 497-515, 1966. [The regime of the energy budget at the ocean surface and in the upper mixed layer accounts for a major difference between the Southern and Northern hemispheres. Cf. ref. I B-13.]

[For other studies of oceanic energy budgets, see references in Sections III E and F; for the role of the oceans in the carbon cycle, see II C-2. For comparison with energy storage in lakes, see III D-13 to 16 and VIII B-28.]

G. Changes in Climate, particularly in Atlantic Europe

1. Manley, G. "Climate fluctuations and fuel requirements." Scottish Geographical Magazine 73: 19-28, 1957. [Variation from winter to winter can be expressed as variation in the energy cost of house-heating, and this again in fiscal terms comparable in size to the deficit in the nation's balance of payments.]

2. Namias, J. "Surface-atmosphere interactions as fundamental causes of drought and other climatic fluctuations." Arid Zone Research 20: 345-359, 1963. [With examples of effects of abnormal extent of snow cover, dry soil, and sea-surface temperature on atmosperhic heating. Cf. refs. III E-10 to 13.]

3. Lamb, H. H. "On the nature of certain climatic epochs which differed from the modern (1900-39) normal." Arid Zone Research 20: 125-150, 1963. [Pre-instrumental records of climate can be used to determine severity of mid-winters and moisture conditions of mid-summers, both conditions being related to positions of troughs and other flow characteristics aloft.]

4. Lamb, H. H. The Changing Climate. London: Methuen, 1966, 236 pp. [Papers on effects of longitudinal extent of snow cover on the location of a cold trough aloft, and many other aspects of climatic change. See also idem, "Britain's changing climate," Geographical Journal 133: 445-468, 1967.]

5. Murray, R., and Lewis, R. P. W. "Some aspects of the synoptic climatology of the British Isles as measured by simple indices." Meteorological Magazine 95: 193-203, 1966. [Indices based on frequency of days with cyclonic or anticyclonic flow, westerly or blocked flow, and so on, are useful in comparing individual months, years, and decades of the past ninety years. (Cf. the index in item VII B-3.)]

6. Smith, L. P. "The significance of climate variations in Britain." Arid Zone Research 20: 455-463, 1963. [Small changes at critical times in the farming year can give a lot of trouble, especially if they have not been taken into account in the management pattern.]

7. Johnson, C. G., and Smith, L. P., editors. The Biological Significance of Climatic Changes in Britain. London and New York: Academic Press, for the Institute of Biology, 1965. 222 pp. [Problems at different seasons in farm operations and fishing that may come

with even a small down-turn in heat supply. Papers of special interest include:

Lamb, H. H. "Britain's changing climate." 3-34;

Blaxter, K. L. "Climatic factors and the productivity of different breeds of livestock." 157-168 [with heat budgets of farm animals];

Cooper, J. P. "Climatic adaptation of local varieties of forage grasses," 169-179 [the role of solar radiation];

Smith, L. P. "Possible changes in seasonal weather," 187-191 [and the threats they present to farming operations];

Duckham, A. N. "Agricultural perspectives: short-term climate change and the farmer," 193-201 [four food chains, each differently affected by changes in climate.]

8. Taylor, J. A., editor. Weather and Agriculture. New York: Pergamon Press, 1967. 225 pp. [Includes papers on soil climate, agricultural productivity, and weather effects on specific diseases. "Weather and farm management decisions," by A. N. Duckham, identifies weather-sensitive aspects of farm operations.]

9. Manley, G. "The revival of climatic determinism." Geographical Review 48: 98-105, 1958. ["It is an opportune moment to be reminded that man is still subject to a variety of constraints. . . ."]

10. Sewell, W. R. D., editor. Human Dimensions of Weather Modification. University of Chicago Department of Geography Research Paper No. 105, 1966. 423 pp. [A series of papers that suggest that we consider some possible consequences before we plunge ahead with modifications of weather just to find out what we can do. Papers 8-10 go into the costs and possible benefits of modifications; 22 and 23 discuss our perceptions of modification; 27, by Marston Bates, examines the role of weather in human behavior. Paper 5, by E. A. Ackerman, points out the joint interaction of meteorology and economics in the "great biotic system that men and their society now dominate."]

11. Sargent, F., II. "A dangerous game: taming the weather." Bulletin of the American Meteorological Society 48: 452-458, 1967. [Discusses threats to ecosystems as natural resources, that stem from our inability to forsee the results of weather modification. "To construct a mathematical model of a complete ecosystem requires far more detailed knowledge than we now possess."]

12. Whittaker, R. H. "Ecological implications of weather modification." In: Ground Level Climatology, R. H. Shaw, editor. Washington: American Association for the Advancement of Science, Publication No. 86, 1967, 367-384. [Complex, nonlinear, and "predominantly detrimental" effects of weather modification on natural communities, and very likely on man. Cf. ref. V A-9.]

UNIT VIII

H. World-wide Aspects

1. Crowe, P. R. "The geographer and the atmosphere." Transactions of the Institute of British Geographers 36: 1-19, 1965. [A clarifying discussion of air masses as concepts, and of the general circulation. A presidential address.]

2. Vuorela, L. A., and Tuominen, I. "On the mean zonal and meridional circulations and the flux of moisture in the Northern Hemisphere during the summer season." Pure and Applied Geophysics 57: 167-180, 1964.

3. Haines, D. A., and Winston, J. S. "Monthly mean values and spatial distribution of meridional transport of sensible heat." Monthly Weather Review 91: 319-328, 1963. [Poleward movement of energy as latent and sensible heat.]

4. Mitchell, J. M., Jr. "Theoretical paleoclimatology." The Quaternary of the United States, H. E. Wright, Jr., and D. G. Frey, editors. Princeton University Press, 1965, 881-901. [Factors that determine climate, including the energy budget at different latitudes, and the "geographic factors" of albedo, heat capacity, and relief.]

5. Flohn, H. "Theories of climatic change from the viewpoint of the global energy budget." Arid Zone Research 20: 339-344, 1963. [Changes in the circumpolar vortex—its expansion and contraction, its breakdown in blocking situations, and its meanders "can only be completely understood on the basis of the energy budgets of the atmosphere and . . . the oceans." Cf. references in Sec. I B.]

6. Curry, L. "Climatic change as a random series." Annals of the Association of American Geographers 52: 21-31, 1962. [Random variation in climate, especially when allied with energy storage and feedback, may simulate a real climatic change.]

7. Dzerdzeevskii, B. L. "Fluctuations of climate and of general circulation of the atmosphere in extra-tropical latitudes of the Northern Hemisphere and some problems of dynamic climatology." Tellus 14: 328-336, 1962. [A system of typing circulation patterns is applied to delimit periods or epochs within which climatic classifications ought to be confined.]

8. Rigby, M. "The evolution of international cooperation in meteorology (1654-1965)." Bulletin of the American Meteorological Society 46: 630-633, 1965.

9. Spacecraft in Geographic Research. National Academy of Sciences—National Research Council, Publication 1353, 1966. 107 pp. [On the truly international character of the study of the earth's atmosphere (Rigby) and its surface ("Spacecraft"). In "Spacecraft," the section on the energy and water budget, plant cover, and resource utilization may be useful.]

10. Flohn, H. "Zur Frage der Einteilung der Klimazonen." Erdkunde 11: 161-175, 1957. [An excellent review of the climatic implications

of what is known about the general circulation, with attention to the conflict between ideas of a zonal and a cellular pattern. Also discusses other methods of classifying world climate. This paper is probably the best single reference on the vexed subject of climatic classification.]

11. Kung E. C. "Large-scale balance of kinetic energy in the atmosphere." Monthly Weather Review 94: 627-640, 1966. [Generation and dissipation of kinetic energy, especially near the surface.]

12. Landsberg, H. E., "Climate made to order." Bulletin of the Atomic Scientists 1961: 370-374. Reprinted in: Physical Geography: Selected Readings, F. E. Dohrs and L. M. Sommers, editors, New York: Crowell, 1967, 73-80. [Discusses proposed interferences with the heat budget at the surface and the water budget of the atmosphere, and the necessity to do computer modelling of their effects before trying field experiments.]

13. Gerasimov, I. P., and Glazovskaya, M. A. Fundamentals of Soil Science and Soil Geography. Jerusalem: Israel Program for Scientific Translations, 1965. 382pp. [Soil formation, affected by heat and moisture regime and biological productivity, exhibits regularities over the world that are related to the surface budgets of energy. water, and nutrients.]

14. Budyko, M. I., and Gerasimov, I. P. "The heat and water balance of the earth's surface, the general theory of physical geography and the problem of the transformation of nature." Soviet Geography 2, No. 2: 5-12, 1961. [Implications of the budget for methodology and applications.]

15. Barrett, W. J. Manual for the Geography of Natural Resources. Minneapolis: Burgess, 1963. [Employs energy and water budgets, with an excellent set of maps.]

16. "Physical-Geographic Atlas of the World." Soviet Geography 6, No. 5-6, 403 pp. 1965. [Translation of legends and explanatory text of Fiziko-geograficheskii Atlas Mira, Moscow, 1964, which presents the best available maps of some elements of the energy and water budget and relevant characteristics of the earth's surface. The text contains useful statements of budget methods as well as circulation aspects of climate.]

[Global-scale movements and patterns of matter, other than water substance, also are discussed in budget terms in references II A-3 to 10, and II C-2 and 3. Movements and patterns of water are discussed in IV A-8, in Sections IV D and E, and IV F-15 to 17; those of air flow in I A and B. See, for example, Sutcliffe's (ref. I A-3) Chapter 8. Patterns of energy are described in references on radiation (III C-1, 2, 4, and 5), regional albedo (III C-11 to 13, and III F-6), soil temperature (III D-9), and heating of the atmosphere (III E). The energy budget itself is discussed in references III A-1 to 4, B-6, and B-8.]

UNIT VIII

Problems:

1. In your city, how strong and how far apart are the changes in air streams? How are they perceived by the general public? Students' diaries of front passages or incursions of new air streams would indicate the advective element in climate. It is this element that figures in the kinds of weather forecasts that are made.

2. How far does marine or lake influence penetrate inland, if your city is on a coast? How much of the area from which students commute usually experiences these local advective effects?

3. Anticyclonic air flow brings definite conditions to the surface — a dominance of radiation components in the energy budget, little or no input to the water budget, chance of smog. Students can tally frequencies of days with anticyclonic flow from weather maps, and can then compare their effects on local conditions with those reported in IV E-1 for relation with rain, VII B-3 (p. 55-86) for relations with the energy budget, and VIII G-5 for changes over time.

4. Numbers of regional water budgets have been cast, and are available for students to re-calculate gaps the instructor makes in them. One such budget is for the Delaware basin (Carter, Ref. B-25), and its results might be tied in with later studies on the pollution budget of the river, or the conflict between two large cities for its water.

5. The soil-moisture regime of the Waikato valley (B-1) might be calculated by students for a situation of specified rainfall. On the basis of the other papers on this valley (B-3 to 6), they could then discuss implications of the change in rainfall and soil moisture.

6. Students in cities near the Laurentian Great Lakes should be asked to work at least one water budget for a lake, using the results of the recent revival of interest in these neglected water bodies; see references VII D-19-20 and VIII B-28, in particular. Such a budget gives point to the continuing controversy over the lake level and its relation to Seaway, port, recreation, water-supply and hydroelectric operations.

7. On the U.S. water situation in general, subject of so much loose talk and wild construction proposals, there are lots of data (refs. in Section C), from which students can compare regional demand and supply for specific drainage basins. Those who have a touching faith that our technology can cheaply override limits set in the water budget should be asked to work out some calculations for the future, like those outlined in references C-1, 2, 8, and 9.

8. Antarctic energy budgets, presented in references E-1 to 4, are distinguished by extremely low or negative values of radiation surplus when all wave lengths are considered, although the receipts of solar radiation are not particularly small. What is the reason for the discrepancy between the Antarctic's position as to these two kinds of radiation? If you assume albedo to be 0.7, a value typical of mid-latitude

snow cover, what would be the effect on the radiation budget? What would be the effect if solar radiation decreased by 10 per cent as a result of volcanic dust?

9. Mean budget fluxes for the oceans and continents are given by Budyko in several places (e.g., III A-4 or VIII H-16). From these, students can investigate whether the continents or the oceans are more alike — an interesting question in the global patterning of climate.

10. Zonal averages of the energy fluxes can be arranged in budget frameworks that vary with latitude. Students doing this kind of exercise would gain an appreciation of the latitudinal factor in climate that cuts across the land/sea factor.

11. Maps of global solar radiation, net surplus of whole-spectrum radiation, precipitation, evapotranspiration, and so on, are available in several references cited in this outline. From a comparison of these, students may develop some idea of the relative dominance of latitudinal (zonal) vs. substrate (land/sea) factors. Meshed in with these two contesting factors is the factor of atmospheric circulation. Using Crowe's (H-1) or other maps of air-stream source regions and circulation (see also refs. in Unit I), students can work out relative figures on the contribution of the general circulation in different places. Flohn (H-10) presents maps showing classification by circulation. His own discussion, though unmapped, sets even more specific conditions that would help assess what the circulation contributes in the way of heat and moisture to a specific region and to the shape of the overall pattern.

APPENDIX

Serials Frequently Cited

The interdisciplinary nature of the course means that many references are not from geographic serials, such as those included in items 12 to 32 of A Basic Geographic Library (Commission on College Geography Publication 2, 1966). Serials not in this list but cited frequently in the references in each teaching unit are named below. Many of these are available in college libraries as a result of government deposit, general library purchases in science, or at the initiative of botany, geology or other departments. Others should be procured for the use of teachers in geography, since they will be found of general value. All are published wholly or principally in English.

Advances in Agronomy (New York)
Advances in Ecological Research (New York)
Advances in Geophysics (New York)
Agricultural Meteorology (Amsterdam)
Agronomy Journal (Madison)
Air Pollution Control Association, Journal (Pittsburgh)
American Geophysical Union, Transactions (Washington)
American Meteorological Society, Bulletin (Boston)
American Society of Civil Engineers, Transactions, and Journals of Divisions (New York)
Archiv für Meteorologie, Geophysik, und Bioklimatologie, Serie B (Wien)
Arid Zone Research (Paris)
Australian Geographer (Sydney)
Australian Geographical Studies (Melbourne)

Ecology (Durham)
Ecological Monographs (Durham)

Geographical Bulletin (Canada)

International Journal of Biometeorology (Amsterdam)

Journal of Applied Meteorology (Boston)
Journal of Geophysical Research (Washington)
Journal of Hydrology (Amsterdam)
Journal of Soil and Water Conservation (Ankeny, Iowa)

Meteorological Magazine (London)
Meteorological Monographs (Boston)
Monthly Weather Review (Washington)

New Zealand Geographer (Christchurch)

Oikos (Copenhagen)

Publications in Climatology (Centerton, N.J.)

Royal Meteorological Society, Quarterly Journal (London)

Science (Washington)
Scientific American (New York)
Soil Science Society of America, Proceedings (Madison)
Soviet Geography (New York)
Soviet Hydrology (Washington)
Soviet Soil Science (Madison)

Tellus (Stockholm)
Tokyo Journal of Climatology (Tokyo)

United States:
Department of Agriculture, Yearbooks, Technical Bulletins

Geological Survey, Water-Supply Papers; Professional Papers, Hydrologic Atlases

United States: continued

Public Health Service, Air Pollution and Water Pollution Reports

Weather Bureau, Technical Papers, Research Papers, Translations by the Office of Climatology

Water Resources Research (Washington)

Weather (London)

Weatherwise (Boston)

World Meteorological Organization, Technical Notes (Geneva)