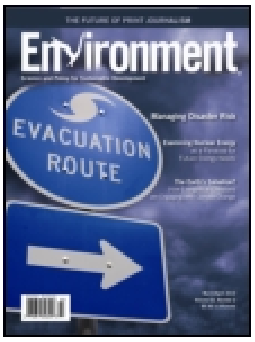

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Development in Arid Lands Lessons from Lake Chad

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DEVELOPMENT IN ARID LANDS

Lake Chad was once the second largest wetland in Africa. Because of a series of droughts that began in the 1960s, however, the lake has shrunk to almost one-tenth of its maximum area. The demise of Lake Chad and the resulting impact on the local economy and environment have caused concern among the nations that share its waters—Cameroon, Chad, Niger, and Nigeria—and has prompted action at both the regional and international levels.

At the regional level, the Lake Chad Basin Commission (LCBC) was created in 1964 to regulate and coordinate water-use projects among the countries that occupy the basin. Although LCBC remains a positive force in the region, it has relatively little power, and its effectiveness varies with its funding.[1]

An international program for the Lake Chad basin was begun in 1988 under the Environmentally Sound Management of Inland Water (EMINWA) program of the United Nations Environment Programme. EMINWA assists governments in integrating environmental concerns into the management of water resources. EMINWA also has produced an action plan for the Zambezi River basin in southern Africa and is conducting a diagnostic study of the Aral Sea in central Asia. The value of such studies is twofold. First, a sustained sequence of studies helps to identify and document the type, magnitude, and causes of the most pressing environmental problems. Second, such studies are performed in cooperation with the various governments and agencies that ultimately control natural resource management within a basin. Thus, although change is sought that will benefit the natural environment, proposed changes are tailored to fit the social, political, and economic environments of participating countries.

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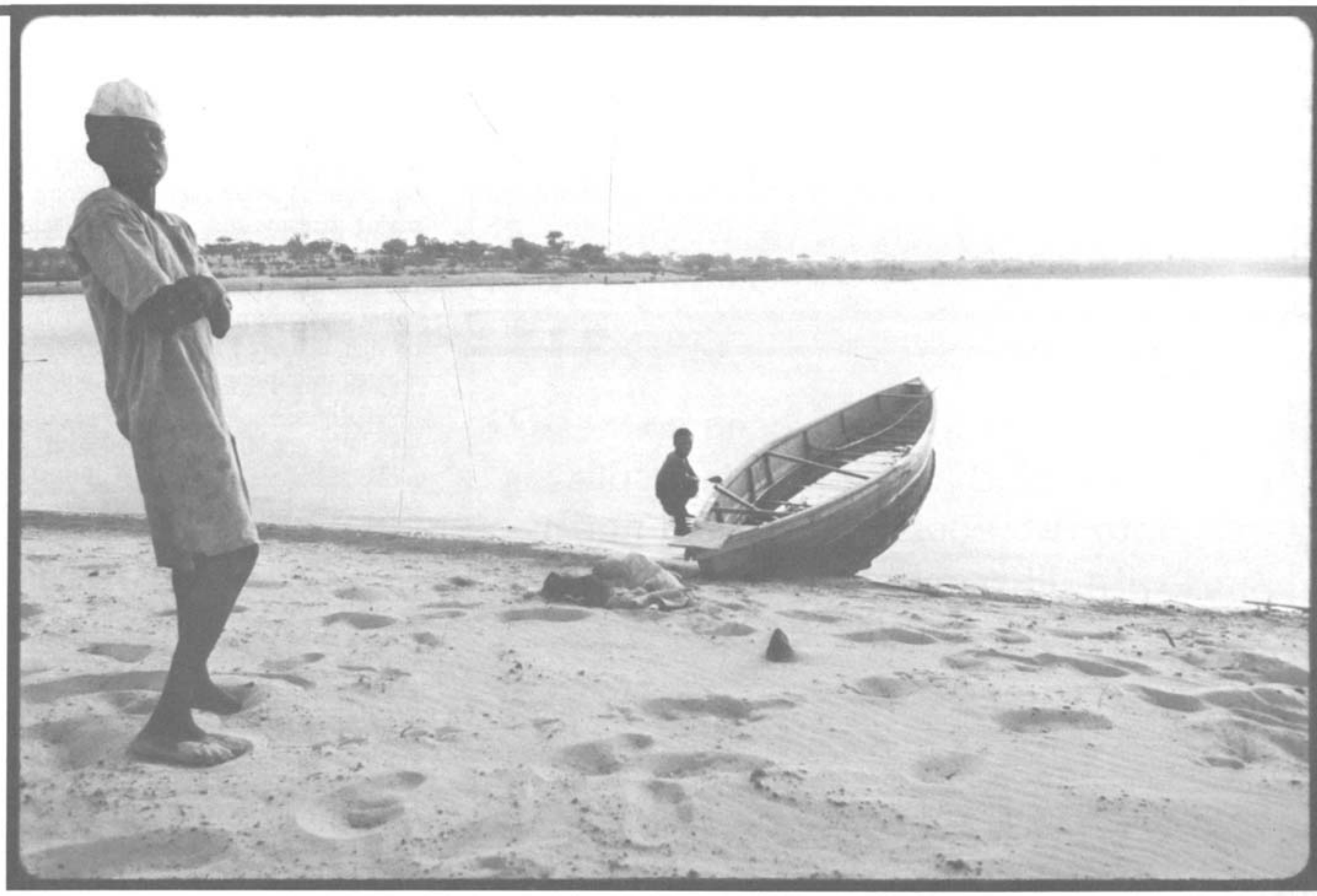
The Lake Chad Basin

Stretching northward across the Sahelo-Sudanian zone into the Sahara Desert, Lake Chad is a geographic anomaly: a large expanse of freshwater lying on the edge of the largest and driest desert on Earth (see Figure 1 on page 19). Yet, despite this potentially harsh location, the Lake Chad basin is a highly productive wetland that supports a diverse wildlife population, including elephants and hippopotamuses, and serves as a major resting ground for intra-African and intercontinental migratory birds.[2] The basin also is the focal point of a variety of human activities.

Lessons from Lake Chad



UNDP—RUTH MASSEY

by Charles F. Hutchinson, Peter Warshall, Eric J. Arnould, and Janusz Kindler

The climate of the Lake Chad basin ranges from semi-arid to arid. The source of the lake's water is run-off from mountains far to the south, in the humid uplands of southern Cameroon and the Central African Republic. Of Lake Chad's five principal tributary basins, the Chari and Logone rivers alone account for about 80 percent of the lake's annual inflow, which is around 40 cubic kilometers, under normal conditions. Altogether, 99 percent of Lake Chad's water comes from river inflows.[3]

Although Lake Chad has a relatively low-lying outlet in the southeast at the Bahr el Ghazal River in Chad—284 meters above sea level—the average lake level is just 280 meters above sea level. In fact, there probably has not been any outflow from the lake since 1875. As a closed basin, with estimated annual evaporation rates ranging between 2,200 millimeters and 2,800 millimeters, the quality of water in Lake Chad, in terms of the amounts of both suspended and dissolved solids, is surprisingly good.[4] This quality is due, in large part, to the low concentration of dissolved solids carried by the Chari River system, which is about half the average of the world's major streams. Much of the suspended solids are removed from the inflow as it spreads across the floodplain of the Chari and Logone rivers, before entering the lake. Once in the lake, the solids react to reduce the water's acidity, and some dissolved solids, such as calcium and silica, are removed through chemical precipitation or incorporation by mollusks, diatoms, and other plant and animal life. Finally, between 4 and 6 percent of the inflow, along with a portion of the dissolved solids, is lost through soil infiltration.

The water loss has been so extreme that the lake has split into two pools—south and north—with different elevations.

The most dramatic change in the basin has been the recent decline in Lake Chad's surface area. The lake's level fell from 283 meters above sea level in 1963 to 276.6 meters above sea level in 1986, which caused the lake's area to diminish from 25,000 square kilometers to less than 3,000 square kilometers. Within this period, however, there was considerable fluctuation in area, which continues today.[5] Nevertheless, the water loss has been so extreme that the lake has split into two pools—south and north—with different elevations.

Agricultural Development's Role

A search for the causes of the dramatic decline of Lake Chad has revealed some familiar suspects. Lakes in arid and semi-arid environments around the world have been threatened by agricultural development during the latter half of this century. The Aral Sea in central Asia has been the most notorious.[6] Like Lake Chad, the Aral Sea occupies a basin and was maintained by river inflows. However, vigorous irrigation development by the Soviet government in the upper reaches of the Aral watershed diverted virtually all the water to agricultural projects. The resultant shrinkage of the Aral Sea has caused an increase in salinity levels and a concentration of waterborne agricultural contaminants and has led to a destruction of the fishing industry, severe health problems associated with diminished water quality, and increased mobilization of windborne contaminated sediments.

Like the Aral Sea, the Lake Chad basin is large, but it is also very flat, and the lake is shallow—rarely exceeding 7 meters in depth. As a result, the surface area of the lake varies wildly in response to even small changes in its volume. This fluctuation causes some scientists to argue that the term *lake* is inaccurately applied to Lake Chad and that it may be more useful to think of the area as a deep wetland, particularly because most fish species evolved from river-adapted, rather than endemic, species.

Traditionally, some agriculture in the Lake Chad basin has been conducted in upland rain-fed fields, when rain is plentiful. More reliable production and higher yields, however, come from low-lying areas that are seasonally flooded by tributary streams. Most of this activity occurs along the Chari and Logone rivers in Chad and Cameroon. In addition to crop production, undeveloped land in these areas is also used as pasture.

Because of the lake's high-quality water resources, a number of large irrigation projects have been planned in the most favorable areas of the basin. Although some small projects have been proposed that would be based on dams and canals, the low terrain of the basin dictates that most of the development projects should be of two types. One type is the irrigated perimeter, or a diked area fed by pumped water, located along a major stream and often displacing traditional fields. The other type is found around the lake itself and relies either on water pumped from the lake or that delivered by gravity to fields located in impoundments, or polders, along the lake edge. In either case, lake level is a critical design factor.

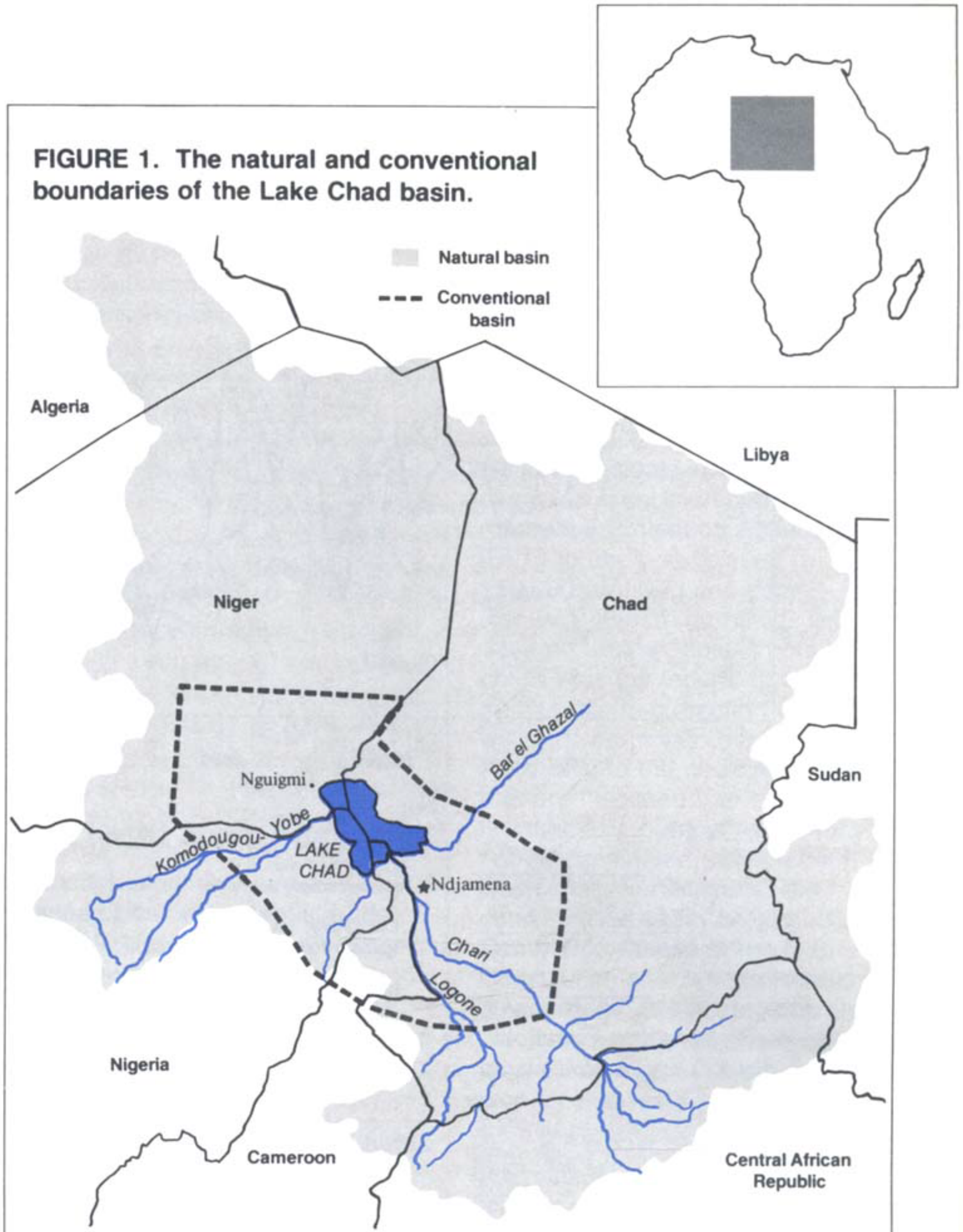
At least 20 agricultural projects comprising a total of perhaps 500,000 hectares have been planned at various times within the immediate basin. However, only about one-fifth of this area has been developed. Thus, at least for now, the actual demands placed upon the water resources that sustain Lake Chad are comparatively modest overall but may be quite significant during periods of low flow, for sensitive habitats, or for smaller river systems. The Komodougou-Yobe River, between Nigeria and Niger, is an example of a small river system from which essentially all flow has been diverted upstream, thus depriving the northern pool of Lake Chad of its only tributary. A similar situation has occurred south of the lake, at the Maga Dam in Cameroon, which has reduced downstream flooding of the Grand Yaeres floodplains of the Logone River and caused some perennial plants to be replaced with annuals. Moreover, the dam has restricted adversely available habitat for livestock and wildlife, particularly elephants, and floodplain farming conducted in the area has been affected by reduced flooding. However, the impacts of development appear to be felt most in local livelihood systems. Rather than directly causing Lake Chad to shrink, agricultural developments, it can be argued, are directly and indirectly amplifying the human distress and environmental damage associated with recent droughts.

The Role of Climate

Although agricultural diversions have played a role in reducing Lake Chad and significantly affecting the area, climate has historically been the dominant factor in determining the area occupied by the lake. Arid and semi-arid climates are marked by low absolute amounts of and extreme variability of rainfall. Thus, because Lake Chad sits along a very steep south-to-north rainfall gradient, the average rainfall slightly south of Lake Chad at Ndjamena, for example, is 578 millimeters, while just 200 kilometers away, at Nguigmi, Niger, which was at the northwestern tip of the lake prior to the drought, the average annual rainfall is only 219 millimeters.

Rain comes to the area when the Inter-Tropical Convergence Zone (ITCZ) moves north each summer. The amount of rain is determined, in general, by the duration of ITCZ. As might be expected, the northward limit of the ITCZ varies from year to year. However, because of the steepness of the precipitation gradient, these relatively minor variations can have profound impacts on rainfall patterns in the vicinity of the lake as well as in the headwaters of the Chari and Logone rivers (see Figure 2 on page 20).

FIGURE 1. The natural and conventional boundaries of the Lake Chad basin.



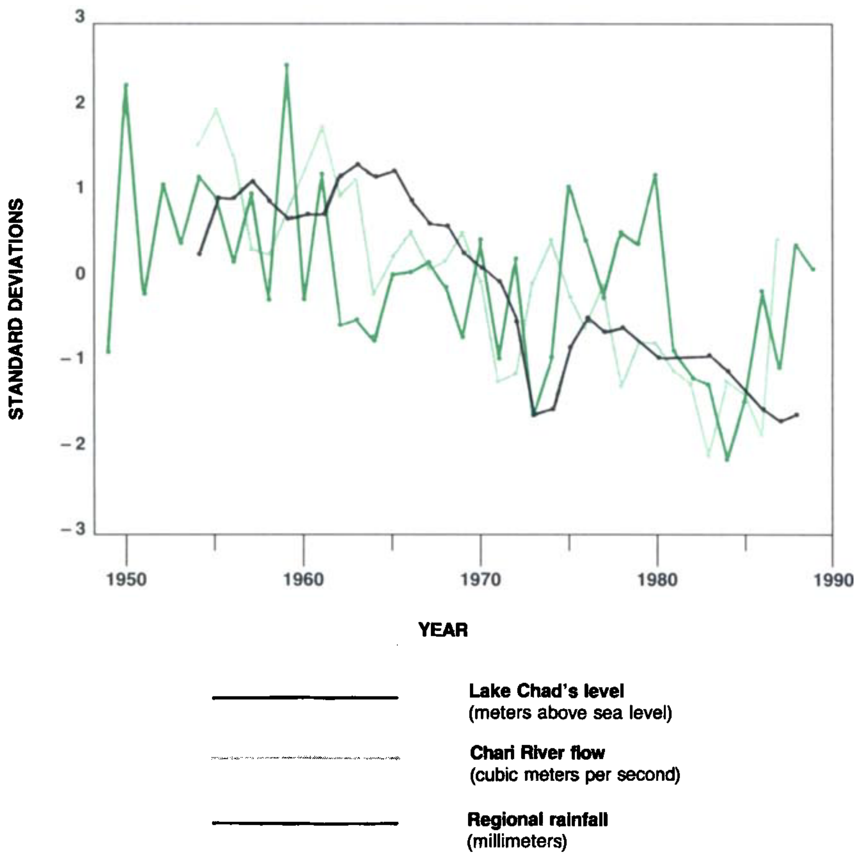
SOURCE: J. Kindler et al., *The Lake Chad Conventional Basin: A Diagnostic Study of Environmental Degradation* (Tucson, Ariz.: University of Arizona, Office of Arid Land Studies, 1990).

As a consequence of climatic variability, Lake Chad has swollen and shrunk in response to the pulse of regional climate patterns over the past 20,000 years. Because of its sensitivity to fluctuations in rainfall patterns, Lake Chad has been the subject of considerable study by climatologists concerned with regional climate patterns.[7] The magnitude of this variability largely outweighs the changes in inflow volume brought about by agricultural withdrawals, at least for now. However, as the number of development projects increases and the volume of water that is withdrawn or diverted grows, the impact on Lake Chad itself will increase as well.

Primary Impacts

The drought and subsequent decline in river discharges and the level of Lake Chad have had predictable adverse environmental effects, most of which have a number of direct impacts on wildlife habitat. For instance, because of the reduction in lake area, resuspension has occurred for some sediments, which adversely affects the substantial lake fishery. Moreover, the separation of the lake into two pools inhibits the movement of water and fish, and, for example, when the north pool finally disappears, so will the fish. Also, as the lake's size diminishes, predation on fish becomes easier. Fortunately, both pools are restocked with river

FIGURE 2. Lake Chad's level, Chari River flow, and regional rainfall.



species whenever the lake refills.

As in-stream flows decline and groundwater tables drop, the tree and shrub species that rely on shallow water resources suffer. In addition, during a drought, the practice of burning rangelands to improve fodder production increases the frequency and intensity of wildfires in the tree and brush savannas. These factors, combined with increased woodcutting, place severe pressure on the remaining vegetative resources. Similarly, as the basin dries and surface water resources diminish, the terrestrial habitat associated with the lake and its tributary streams retreats. Aside from the simple removal of vegetation, increased damage by wildlife's and livestock's use of favored areas also contributes to the general collapse in habitat quality and availability.

Secondary Impacts

There is little doubt that agricultural developments have added to the direct environmental effects of the drought around Lake Chad by diverting the little water available to other uses. However, many development projects have also magnified the social and economic impacts of the drought, which, in turn, have had negative environmental consequences. Of course, the dominant characteristic of arid lands is not so much limited water availability but the variability of availability. Put another way, the persistent risk of drought is the most important feature of arid lands that affects the livelihood of the people who live there. The livelihoods pursued by the peoples of the Lake Chad basin, including rain-fed and irrigated agriculture, herding, and fishing, are adapted to the area's climatic features, such as extremely variable rainfall, low absolute amounts of rainfall, and related fluctuations in stream flow and lake levels.

In general, indigenous production strategies have two features. First, they take advantage of water when and where it is available. Second, they are multifaceted in that they diminish risk by combining several productive enterprises, such as irrigated or rain-fed agriculture and herding, or by diversifying one enterprise—for example, by maintaining a diverse herd composition to exploit different environments—rather than focusing all efforts on just one enterprise. Thus, a single family may be involved in several different enterprises, each in a different physical environment and often spread over considerable distances. Frequently, if the growing season is especially good or poor, some of these resources, such as rain-fed fields, may not be exploited in a given year. Generally speaking, traditional indigenous strategies tend to be resource conservative.

In addition to the diversity of traditional systems, there are alternative systems, or coping mechanisms, that are employed during times of emergency.[8] Emergencies, moreover, may be precipitated by a host of factors other than drought, such as war or civil unrest, which have been particularly widespread in Chad during the past decade. Some of the more common coping mechanisms include consuming "famine," or wild, foods rather than crops, and changing herd composition from larger animals to smaller ones. For example, after the droughts of the early 1970s, many farmers in the Lake Chad basin changed from herds dominated by cattle and camels, which are largely grazers, to herds of mostly sheep and goats, which are largely browsers. However, because the drought continued, herds could not be reconstituted, and tree and shrub populations were heavily browsed during the 1984 drought. As a result, few woody juveniles were

(continued on page 40)

Lessons from Lake Chad
(continued from page 20)

able to re-establish, and the composition and structure of the habitat changed. Other coping mechanisms include increased harvesting and sale of "wild" products, such as fuelwood or charcoal. For example, residents of Ndjamena purchase fuelwood cut as much as 120 kilometers away. This action, however, appears to be as much a consequence of war and political instability as of drought.

The ultimate coping mechanism is migrating to areas that are comparatively better endowed. Some of these areas might be urban centers, where employment opportunities exist; others might be local environments. The number of villages found on the Nigerian section of Lake Chad, for example, grew from 40 in 1975 to more than 100 in 1988—a period that included two severe droughts. Similarly, pastoralists seeking refuge from the drought entered the area near the lower Chari River and thus caused conflicts among the refugees and with local agriculturalists and created an outbreak of animal diseases.[9]

Although there is an apparent increase in the use of coping mechanisms, some situations serve to reduce their effectiveness. For example, many of the most basic coping mechanisms are based on mobility, such as the movement of animals and people to seasonal pastures or more favored areas, the migration of males to places of possible employment, and the migration of entire families to relief centers. Any condition that might impede mobility limits the range of coping mechanisms available to households. Thus, aside from its direct impacts, even the threat of civil unrest—whether real or perceived—restricts household options and increases the vulnerability of families to potential economic or food security emergencies.

Although they help people endure emergencies, the most extreme coping mechanisms, such as overgrazing, woodcutting, and charcoal production, will likely have adverse environmental consequences if used over an extended period of time. Moreover, if the number of coping mechanisms available to a population is restricted arbitrarily through government policies—limitations on the movement of pastoralists, for example—or because of civil unrest, as in the case of Chad, reliance on the remaining coping mechanisms increases. Thus, those available natural resources become proportionally more in demand. In the face of persistent droughts, growing populations, and unstable governments and economies, coping mechanisms have become a routine part of the production strategies of households in the region.[10]

Because of the wide-ranging connections between diversified household enterprises and mechanisms used for coping with emergencies, modern development schemes often disrupt the balance between climate and the inherent risk of drought, the productive use of the land, and the maintenance of wildlife and the environment in general. This disruption happens in several ways.[11] First, almost all large agricultural projects commonly focus on the development of only one productive enterprise, such as irrigated agriculture, and one high-value crop, such as rice, at the expense of the other production opportunities on which traditional systems rely. Such large projects require a significant reorientation of family resources. For example, financing for irrigation schemes around Lake Chad is usually based on an assumed production of at least two crops per year, which diverts labor and capital from the traditional mix of annual enterprises conducted by the family. Thus, the farmer's exposure to risk is enhanced by reducing the diversity of the family's investment.

Second, development projects frequently preempt land uses that previously had played important roles in local production strategies. For example, some seemingly unused areas may, in fact, be cultivated when they receive favorable rainfall or flooding.

LEO DE WYS, INC.—RICHARD SAUNDERS

The number of Nigerian villages along Lake Chad increased by 150 percent between 1975 and 1988, despite two severe droughts.

INTERNATIONAL WILDLIFE COALITION—STEPHEN BEST

The steady decline of Lake Chad has adversely affected the populations of many native animal species, including hippopotamuses.

Although it is possible to view these lands as unused during any given year and, thus, as available for development, they are an integral part of the agricultural system. The development of these reserve lands increases the farmer's exposure to risk by reducing the diversity and, hence, the viability of the existing system.

Finally, development is carried out on the assumption that the water to be exploited is currently underused, unused, unproductive, unallocated, or, at least, uncontrolled. As is seen in the case of development around Lake Chad, it is difficult to determine where any excess water might be found, aside from evaporation. It can be argued, however, that water control systems may reduce exposure to risk by creating storage reserves to meet periodic shortages. Although this method has achieved success in the industrial world, it has failed in developing countries for at least two reasons. First, the loans required for large developments will not likely be repaid, given the low economic returns and propensity for failure of such projects in developing nations.[12] The second and most compelling reason is that, although the inherent variability of arid climates is understood by climatologists, it seems to be routinely ignored or underestimated by developers. Consequently, the impact of drought and the decline of Lake Chad has been intensified by the failure of development projects built on the mistaken assumption that river flows and the lake's level would remain more or less constant, or at least would vary within an acceptable range.

Development projects frequently preempt land uses that previously had played important roles in local production strategies.

Planning for Drought

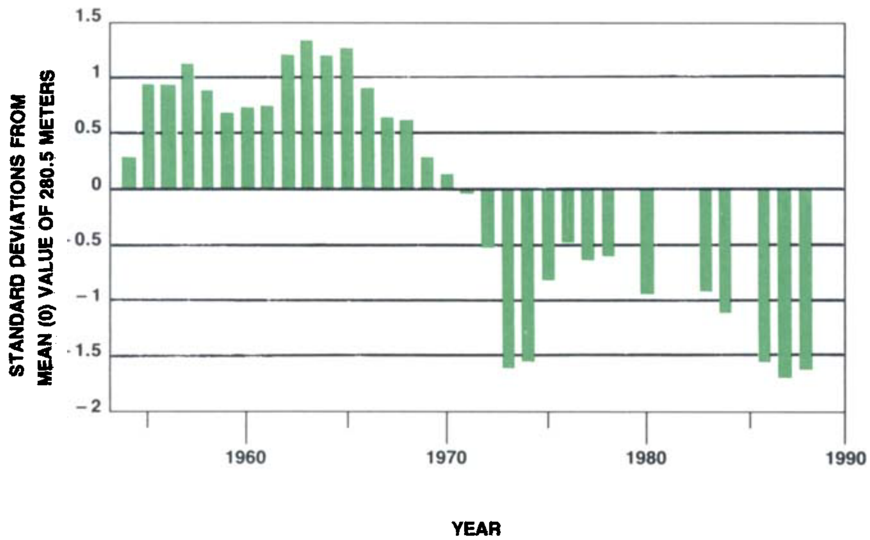
The case for recognizing climate as a fundamental variable in development planning has been argued for some time.[13] The need for this perspective is perhaps best illustrated by the case of the South Chad Irrigation Project (SCIP), constructed by the Nigerian government along the southwestern shore of Lake Chad.[14] As the largest irrigation project in Nigeria, SCIP was designed in the early 1960s to encompass 67,000 hectares of land and involve 55,000 farming families, who would grow wheat in the winter and rice or cotton in the summer. Because the project was intended to draw water from the lake to irrigate the surrounding lowlands, the lake level was a critical variable in the project's design. In 1971, an average minimum water level of 279.9 meters was assumed in the design for SCIP. Immediately following the project's design, the region suffered a series of droughts and record-low lake levels. By the time SCIP was launched, lake levels had recovered but only to the minimum level assumed in the design.

This situation prompted the following note in the SCIP inauguration brochure:

Hydrological studies show that lake levels over 1870–1970 have, on the whole, been at a higher level than now prevails; it seems logical therefore to regard the droughts of the early 1970s as temporary aberrations rather than indicating new low norms.[15]

Because of the lake's low level, SCIP operated for only 6 of the next 10 years, irrigating a maximum of only 7,000 hectares during that time. Al-

FIGURE 3. Lake Chad's minimum levels



SOURCE: Direction des Resources en Eau et de la Meteorologie, Ndjamena, Chad.

though there have been recurring logistical problems, such as a lack of power to operate the pumps, the major factor contributing to the overall failure of the project is design. Lake Chad failed to remain at the 279.9-meter minimum level around which SCIP was designed (see Figure 3 on this page).

It is important to note that design work on SCIP began at the end of a relatively wet period. Moreover, the data record for lake levels is quite short, and the design's minimum level was assumed to be reasonable based on data for more humid, less variable environments. However, instrumental observations from the early part of this century, historical accounts of drought, reconstructions of the lake level using Nile River flows, the climate record, and a geologic record of wide swings in Lake Chad's level—all describe variability that exceeds the data contained in the instrumental record.[16] In the face of this other, noninstrumental evidence, the assumption that the "normal" behavior for an arid climate is anything other than extreme variability is difficult to defend. It would appear that the designers' desire to maintain low overall project costs was greater than their concern over the possibility of drought.

With this design failure, production on SCIP, even in good years, is limited to winter wheat because summer lake levels are too low to permit irrigation of more highly valued crops, such as rice and cotton. As a result, agricultural production intensity and, hence, returns seldom exceed half of that projected for the cultivated areas. From an investment standpoint, the performance of SCIP to date is a considerable economic blow to Nigeria and the lake region. However, with an understanding of the existing diverse production systems in the region, it is possible to argue that the failure of the project has far-reaching, severe impacts of comparable magnitude on both the population of the area and the Lake Chad environment.

The Lessons of Lake Chad

Among the many lessons that might be learned from the recent decline of Lake Chad and the development that has occurred in the basin, three in particular have a bearing on the sustainable development of arid and semi-arid lands. First, climate must be considered as a variable rather than as a constant in planning economic development projects in arid and semi-arid lands. Second, when the availability of a fundamental resource, such as water, is the primary constraint to development, expansion of any economic activity in any area within the region will have negative impacts on other sectors, other areas, and perhaps other regions. Finally, without intervention, the decline in productivity of any economic sector will have negative environmental consequences if the local population is forced to abandon resource-conservative strategies and rely increasingly on nonsustainable uses of natural resources for food and income.

Climate must be considered as a variable rather than as a constant in planning economic development projects in arid and semi-arid lands.

NOTES

1. The Lake Chad Basin Commission was formed with support from the United Nations Development Programme and the United Nations Sudano-Sahelian Office as an outgrowth of the Convention of Fort Lamy (now Ndjamena), which was signed in 1964. Moved by the dramatic shrinkage of Lake Chad, the African Ministerial Conference on the Environment helped the commission develop the resources of the basin in a more integrated fashion. As a preamble, the Water and Lithosphere Unit of the United Nations Environment Programme conducted a reconnaisance study in 1988. In 1989, a follow-up diagnostic study was commissioned for the basin commission with support provided by UN organizations. This article is drawn from the final report of the project by J. Kindler et al., *The Lake Chad Conventional Basin: A Diagnostic Study of Environmental Degradation* (Tucson, Ariz.: University of Arizona, Office of Arid Lands Studies, 1990).

2. For a general discussion of the nature of Lake Chad, see A. T. Grove, "Rise and Fall of Lake Chad," *Geographical Magazine* 42 (1964):432–37.

3. A good summary of water quality and balance and biogeochemical processes at work in Lake Chad appears in A. T. Grove, "Water Characteristics of the Chari System and Lake Chad," in A. T. Grove, ed., *The Niger and Its Neighbors* (Rotterdam, The Netherlands: A. A. Balkema, 1985), 61–76.

4. Ibid.

5. The nature of the water balance is discussed in S. K. Sikes, *Lake Chad* (London: Eyre Methuen, 1972); and T. E. Evans, "Water Balance Models of Lake Chad" (Paper presented at the International Seminar on Water Resources of the Lake Chad Basin: Management and Conservation, N'Djamena, Chad, 3–5 June 1987).

6. V. M. Kotlyakov, "The Aral Sea Basin: A Critical Environmental Zone," *Environment* (January/February 1991), 4.

7. The extreme variability and size of Lake Chad are discussed in S. E. Nicholson, "The Nature of Rainfall Fluctuation in Subtropical West Africa," *Monthly Weather Review* 108 (1980):473–87; S. Schneider et al., "Monitoring Africa's Lake Chad Basin with Landsat and NOAA Satellite," *International Journal of Remote Sensing* 6 (1985):59–73; and E. A. Rasmussen, "Global Climate Change and Variability: Effects on Drought and Desertification in Africa," in M. H. Glantz, ed., *Drought and Hunger in Africa: Denying Famine a Future* (Cambridge, England: Cambridge University Press, 1987).

8. For a summary of household coping mechanisms, see J. Corbett, "Famine and Household Coping Strategies," *World Development* 16 (1988): 1099–1122.

9. A. Kolawole, "Cultivation of the Floor of Lake Chad: A Response to Environmental Hazard in Eastern Borno, Nigeria," *The Geographical Journal* 154 (1988):243–50; and J. Cabot et al., *Elevage et Potentialitees Pastorales Saheliennes*, vol. of *Synthese Cartographiques: Tchad* (Paris and Wageningen, the Netherlands: Institut d' Elevage et de Medecine Veterinaire des Pays Tropicaux and Centre Technique de Cooperation Agricole et Rural, 1989).

10. For a comprehensive description of coping mechanisms used in northern Nigeria and their long-term environmental consequences, see M. Mortimore, *Adapting to Drought: Farmers, Famines and Desertification in West Africa* (Cambridge, England: Cambridge University Press, 1989).

11. M. M. Horowitz, "Poverty, Development, and the Environment," in H. G. Bohle et al., eds., *Famine and Food Security in Africa and Asia: Indigenous Response and External Intervention to Avoid Hunger* (Bayreuth, Germany: Naturwissenschaftliche Gesellschaft Bayreuth, 1991), 251–66. For a more brief discussion, see C. F. Hutchinson, "Will Climate Change Complicate African Famine?" *Resources* 95 (1989):5–7.

12. M. S. Gould and F. A. Zobrist, "An Overview of Water Resources Planning in West Africa," *World Development* 17 (1989):1717–22.

13. See, for example, D. A. Wilhite et al., eds., *Planning for Drought: Toward a Reduction of Societal Vulnerability* (Boulder, Colo.: Westview Press, 1987).

14. For a critical project review, see A. Kolawole, "Environmental Change and the South Chad Irrigation Project (Nigeria)," *Journal of Arid Environments* 13 (1987):169–76.

15. Sir Malcolm MacDonald and Partners, Ltd., "South Chad Irrigation Project Inauguration" promotional brochure, 16.

16. For an example of reconstructions of Lake Chad fluctuations over the past 20,000 years using precipitation records and neighboring stream flow observations, see D. Jäkel, "Rainfall Patterns and Lake Level Variations at Lake Chad," in N.-A. Mörner and W. Karlén, eds., *Climatic Changes on a Yearly to Millennial Basis* (Dordrecht, the Netherlands: D. Reidel Publishing, 1984), 191–200; for energy and water balance models, see J. E. Kutzbach, "Estimates of Past Climate at Paleolake Chad, North Africa, Based on a Hydrological and Energy-Balance Model," *Quaternary Research* 14 (1980):210–23; for changes in fossil diatom populations contained in lacustrine sediments, see M. Servant and S. Servant-Vildary, "L'Environment Quaternaire du Bassin du Tchad," in M. A. J. Williams and H. Faure, eds., *The Sahara and the Nile* (Rotterdam, The Netherlands: A. A. Balkema, 1980), 133–62; and for historical records of pollen contained in lake sediments, see J. Maley, *Etudes Palynologiques dans le Bassin du Tchad et Paléoclimatologie de l'Afrique Nord-Tropicales de 30,000 Ans à l'Époque Atuelle* no. 129, travau et documents de l'Office de la Recherche Scientifique et Technique Outre-Mer (Paris: ORSTOM, 1981). A recent synthesis of vegetation fluctuations for the region as a function of climate from the Pliocene Age to the present can be found in H. N. LeHouérou, "Outline of the Biological History of the Sahara," *Journal of Arid Environments* 22 (1992):3–30. Despite the geologic record's apparent richness, however, reconstructions based on the document are unlikely to capture relatively short-term variance—less than one decade, for instance—regardless of the lake's magnitude.

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