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World Setting: Paradoxical Constraints on Engineering

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World setting: paradoxical constraints on engineering

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Hundreds of millions of people are suffering from malnutrition and starvation in the Third World, the largest of our worlds. Tens of millions die each year from these causes. Population growth is exponential; growth of food production, at best, is in arithmetic progression, and the gap is rapidly widening.

We need more than scientific training if such immense problems are to be solved. In fact, our scientific and technical training may have left us with some flawed tools.

Droughts are implicit in many of our volatile climates; persistent droughts are also a characteristic of nature and famine is their consequence.

We need to be able to show and to feel that food is worth growing. Aid by the developed nations to the developing nations will not work in the long term without considerable changes in the cultures and technical skills of the poor.

The need

On 29 May 1984, the International Commission on Irrigation and Drainage, at a meeting at Fort Collins in Colorado, heard a remarkable lecture from the Secretary General. This was the Second Gulhati Lecture and, in it, Dr K. K. Framji's theme related to past and probable future developments in irrigation and drainage in developing countries up to the end of the present century (Framji 1984).

The lecture was based on information from many sources, including international aid agencies, other international organizations and reports from the I.C.I.D.'s own national committees in numerous member countries. The sub-title of Dr Framji's lecture was 'Food for all by 2000 A.D.', perhaps because, as he stated, 'the theme is pertinently due for reflection at this decisive juncture'. In it he noted our first paradox, which is that although agriculture originated in the developing countries, their populations today suffer worst from hunger and malnutrition.

It is not appropriate for me to quote at length from Dr Framji's lecture, but the conclusions he reached are apposite in any consideration of the magnitude of what might have to be done.

(i) In Asia alone, 10 million or more children die every year from causes associated with hunger and malnutrition.

(ii) Progress achieved in the Third World in irrigated agriculture has not been commensurate with the efforts made and the *per capita* increase in food production has only been about 10% since the Second World War.

(iii) There is neither the potential nor the scope for achieving self-sufficiency (in food) by 'horizontal expansion' alone but there is much more hope in good management and 'vertical expansion'.

(iv) World population growth is exponential and by the year 2000 is expected to reach 6.2 billion of whom 4.9 billion will be in the developing countries. (In this paper, 1 billion = 10^9.)

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(v) If practices cannot be improved, some 450 million people will be unable to feed themselves by the end of this century.

(vi) Most important, a quotation from Malthus at the end of the eighteenth century (Malthus 1798) is:

> ...population when unchecked increases in geometrical ratio. Subsistence increases only in an arithmetical ratio. A slight acquaintance with numbers will show the immensity of the former in comparison with the latter.

Our training

The theme of this symposium is one that could all too easily tempt a civil engineer into a state of hubris, for we have at our disposal a powerful armoury of apparently scientific concepts and procedures. Indeed, we can only start our professions after a lengthy and quite rigorous training in a considerable range of scientific subjects. However, I hope to avoid the ultimate ruin of the transgressor by stating at the outset that in our training and in our working lives there is a muted insistence that what we are actually to practice is an art, not a science. So it becomes in time and if I exhibit apparently contradictory characteristics, this is the second paradox.

We find ourselves involved in problems for which there are neither clearcut, nor complete, solutions. It takes even longer to become aware that most of the problems cannot be stated completely without recourse to philosophical analogies.

Drought

Suppose, for example, we refer to the word 'drought', which lies like a great spider at the centre of all our (sometimes arcane) concerns and practices in the production of food. We have to accept that it has no absolute meaning in either physical or scientific terms; it can probably be classed as a paradigm.

Nevertheless droughts or shortages of water that are the great destroyers of people in the Third World. There is a good deal of evidence that the occurrence of droughts, which are implicit in the climatic cycle, is not wholly random, although we are normally trained or habituated to deal with hydrological or meteorological happenings as if they were randomly distributed. Not only that, but our technologies can really only deal with random occurrences that fall within tolerable extremes, and that is our third paradox.

Bertrand Russell wrote (Russell 1958):

> Mathematical logic is used in creating structures having assigned properties out of elements that have much less mathematical smoothness.... It has been common among philosophers to begin with how we know and proceed afterwards to what we know. I think this is a mistake because knowing how we know is one small department of knowing what we know. I think it is a mistake for another reason: it tends to give to knowing a cosmic importance which it by no means deserves, and thus prepares the philosophical student for the belief that the mind has some kind of supremacy over the non-mental universe.

Although the amount of rain or other water supply that is insufficient for one crop may be

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sufficient for a different crop at another time, the people who grow crops do not know how much rain they are going to receive, or exactly how much irrigation water will be available, throughout the life of the crop that they have just planted. Nor are they usually in a position to change their ecology quickly. Yet rapid responsiveness is particularly necessary to deal with situations in countries where even annual rainfalls are barely sufficient to grow a seasonal food crop and where there is a tendency for dry, or drought, years to occur in succession, as we are seeing once again, very tragically, in East Africa.

The explanation of the occurrences of extremes in much of the Third World is actually quite simple in theory. It follows directly from the fact that most of the Third World is at the mercy of the difference between two relatively large numbers in climatic terms: rainfall and evaporation. This is the reverse of the situation in most developed countries.

As an example if we consider an area in the Third World where the rainfall average is 100 units per annum and the average potential evaporation from plants and land surfaces is 95 units. There are only 5 units to escape to the rivers or to be stored somewhere against a dry year. If the rainfall in a particular year is 90 units, which can easily happen, the evapotranspiration will try to remain at 95 units, there will be no free water left and vegetation will begin to wilt. If, in another year, the rainfall is 80 units, which will happen frequently, then there will be no free water and many crops will die.

On the other hand, if the annual rainfall is 120 units, which is quite likely, the potential evapotranspiration from the existing vegetations should not change much from 95 units and the residual free water will be multiplied five times to 25 units.

Volatile climates

It will be clear, therefore, why the amount of water available in much of the Third World is essentially a very volatile measure, at least in the places where most people live. It is not usually possible to demonstrate negative values in the water balance quantitatively, although they may be apparent from the drying up of rivers, the death of vegetation and famine.

There are, as far as I know, only two hydrological complexes in which actual negative quantities can be demonstrated by using long-term data. These are the Lake Malawi–River Shire and Lake Victoria–White Nile River complexes in East Africa, both of which I had an opportunity to research some years ago. The behaviour in each is unequivocal but only because both are dominated by the mediating effect of very large natural lakes which act as regulating reservoirs.

My original annual data were tabulated and published (Cochrane 1964). Derived from those data and included here, figure 1*a* shows how the annual free water in the Malawi–Shire complex expressed as a rate of flow between −17500 to +38500 $ft^3\,s^{-1}$. The Victoria–Nile complex is even more volatile and its annual free water has been known to vary from −18060 milliards‡ to +82198 milliards.

In, for example, more temperate southern Britain, we might expect the annual evapotranspiration to be *ca.* 50 units out of *ca.* 100 units average annual rainfall. In such a country it is unlikely that the driest year would produce less than 65 units of rain or that the wettest year

† 1 $ft^3 \approx 0.028\ m^3$.
‡ 1 milliard = $10^9\ m^3$ (water).

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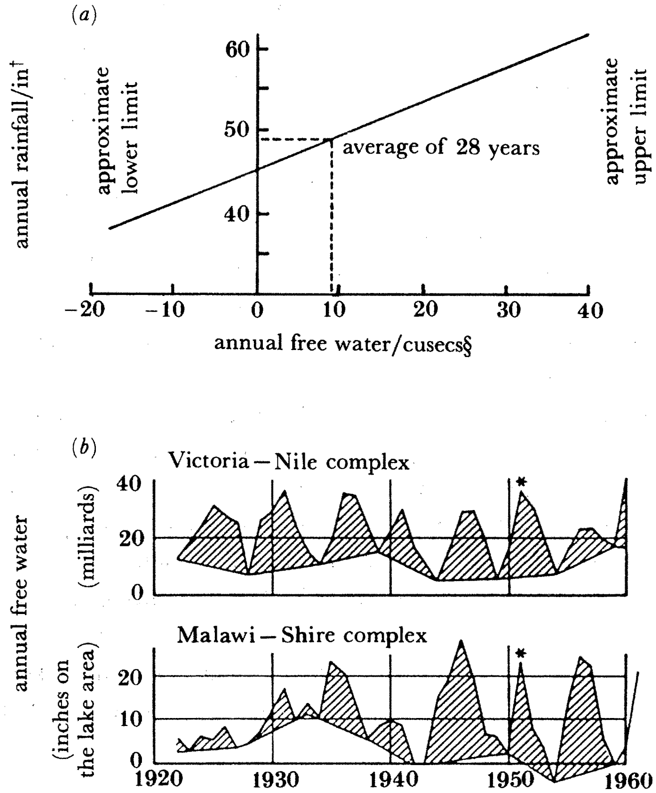

FIGURE 1. (a) Annual rainfall data for River Shire–Lake Malawi complex. (b) Persistent droughts in East Africa; * marks a mean of three years centred on 1951.

would produce more than about 145 units of rain, so the free water level would never be zero nor a minus value but might vary from 15 to 95 units.

AVAILABLE TECHNIQUES

Methods of water analysis and management devised mainly in the temperate zones of the developed world may, in consequence, be barely or rarely completely helpful in the intemperate developing world. They are not the right tools to deal with such low water levels. This leads to our fourth paradox, for there is one further formidable difficulty that may be deduced from the annual data in the two hydrological complexes described above.

PERSISTENCE

One way of reducing the significance of random effects in annual rainfall data is to smooth them into, say, three-year running means, as in figure 1b. This technique also provides a sort of filter for distinguishing a signal from random background noise and in the context of this lecture it shows the strong tendency of drier than average years to clump together persistently in those parts of East Africa. If we are ever to be able to manage such situations we will have to lean very heavily on risk analyses.

§ 'Cusecs' represents a flow of cubic feet per second.

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The consequences for ordinary cultivators of persistent dryness are severe. A farmer's family, which might just exist through the first year of low rainfall, will very probably not survive a second and a third drought year without massive beneficial intervention from outside or vastly improved methods for the long-term storage of food at village level.

Famine

In summary, famine is not a freakish situation; it is implicit in many climates and endemic in many cultures. In the Third World natural water to ensure a food crop does not come in easy, predictable doses. On the contrary, it usually comes either in damaging torrents or in homeopathic doses, and sometimes it comes not at all.

Food price against value

Our fifth paradox stems from the observable fact that it seems universally agreed that food must be cheap and here we confront the dichotomy between price and value, for food and drink are essential to a human being for survival and are in that sense, invaluable beyond price. Yet, analyses of economic advantage or disadvantage of a project are often based on price, not value. The result has been that food has rarely been shown to be worth growing in economic terms and a whole range of expedients has had to be invented to permit food projects for poor people to be contemplated; for example, soft loans, curious discount rates and obscurely derived rates of return.

If, however, it is agreed that a physical development project may be embarked upon, the poor can always be reached by it, for they are part of it. Even success is only temporary, of course, in that consequent increases in the supply of food and potable water lead to an increase in the quality of life and a further increase in populations, which need new projects in their turn. This is our sixth paradox, for it seems that whatever we do to ameliorate, to win, we ultimately find we have lost again.

Summary

I have come to the following conclusions about constraints on development.

(*a*) It is now technically easy for engineers and other professionals to benefit some of the needy for part of the time but not to benefit most of the needy for all of the time.

(*b*) Capital aid or capital investment will not succeed for very long in ameliorating conditions in the Third World, for the implicit environmental problems are too massive and the cultural problems of population growth apparently insoluble and increasing rapidly.

(*c*) Beneficial consequences of the transfer of technological skills are too slow to emerge.

(*d*) To have much effect in our lifetimes, only draconian remedies will achieve much. These seem to me to focus on three immediate aspects: (i) forceful encouragement of birth control in developing countries as has been successful in, for example, Singapore and China; (ii) great reduction in the wastage of crops between the seed in the ground and food in the belly; (iii) more intensive evolution of synthetic proteins and other elements in the food chain by the developed countries.

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