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THE IMPACT OF MODERN IRRIGATION TECHNOLOGY IN THE INDUS AND HELMAND BASINS OF SOUTHWEST ASIA *

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A surface-water irrigation system may be viewed as a three-fold (but four-dimensional) modification of the natural environment, increasing in both area and time the availability of water to the soil.

The distribution network of an irrigation system (canals, branches, laterals, and watercourses) represents a horizontal and essentially linear expansion of the number of channels through which water seeks its own level and, in the process, this network produces a geometric expansion in the area over which this water is in contact with the soil. By far the greatest part of this geometric expansion occurs in the cropped fields themselves, whether the irrigation practiced is of the paddy or the row type. But the wetting of the fields is entermittent, even in rice cultivation where the paddies may be flooded for several weeks at a time, while in row irrigation of cotton, e.g., the soil surface may be wet for only a few hours per week. By contrast, the major distribution channels of a perennial irrigation system are designed to carry water for nine or ten months of the year and, being of much larger cross-section than the watercourses and field channels, make up in volume and in time what they lack in area. [1]

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*Maps of the middle Indus and Helmand basins appear on pages 16 and 17

If the first "artificial" effect of irrigation is to spread a given volume of water over more of the soil surface, its second effect is to lengthen the time which this volume of water spends in contact - or potential contact - with the soil surface.[2] This effect is obvious in any surface-water irrigation system which includes storage dams and reservoirs where one season's or one year's runoff may be largely postponed to the next. But brief reflection shows this to be true even of run-o-the-river systems which do not provide holdover storage. The essence of all gravity-flow irrigation systems lies in decreasing the gradient by diverting water from stream channels at a headworks and causing it to follow a longer and hence slower course to reach a given lower contour. For surface irrigation water to be of any value to crops, it must not only be carried away from the stream channels, but its flow must be slowed down as much as possible. Absorption is a function of time as well as of area, and what cannot be absorbed within the system must either be returned to the rivers or disposed of

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[1]Throughout this discussion, the interrelation of volume and time-- summarized by the irrigation engineer in his terms "second feet," "cusecs," or "cumecs" -- must be kept in mind, for irrigation means the movement of water over time from where it is not wanted to where it is.

[2]So long as an unbroken hydraulic film is maintained, every drop of water above a given point, directly or diagonally, no matter how slight the gradient, may potentially reach that point, just as every drop of water in a bathtub is in potential contact with the drain.

in some other, usually costly, manner. Indeed, the worst nightmare of the superintending engineer is having admitted more water into his system than it can absorb over a given time.

The third modification is a direct result of the first two: by spreading surface water over a much larger area or "command" than it would naturally cover between two points on a stream channel, and by causing it to spend a longer time in the commanded area than it would spend in the stream channel, the irrigator induces a much greater downward movement into the soil than would naturally occur.[3] Part of this movement is beneficial, but once the water has passed both below the root zone of the crops being grown and below the level (approximately ten feet in sandy loams) from which capillary action can raise it to the root zone, it becomes useless. Indeed, it becomes a potential danger to him, for it decreases the amount of "freeboard" available before the groundwater table will rise to interfere with plant growth, or before capillary rise combined with evaporation will increase salt accumulations here or on the surface.

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[3] For the purposes of this paper, such water will be termed "groundwater." The term "groundwater table" or simply "watertable" will be used to designate the interface from which capillary water rises.

> Evaporation causes salts to come over the surface in another way. Where salts are present in the soil at very shallow depths, natural precipitation or insufficient applied irrigation water may penetrate to the level of the saline layer and dissolve it. On subsequent evaporation . . . the salts will appear on the surface. Salts are also present in irrigation water even though in small quantities (150-300 ppm). Continuous application of irrigation water in time may add salts in the soil profile.[4]

Aside from the above-described modifications in the area of channels, in the length of time that surface water remains in contact with the soil, and the resultant increase in the contribution of surface water to groundwater, a number of less obvious but equally significant ecological effects of irrigation should be noted. By expanding the surface area of the water in the system, evaporation is increased. But from the irrigator's point of view, only the stored or diverted water which does not evaporate represents a gain. Efforts are made to reduce evapora-

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[4] M.A. Lateef and R.A. Shamsi, "History and Magnitude of Waterlogging and Salinity Problems in former Punjab, West Pakistan," Symposium on Waterlogging and Salinity (Lahore, West Pakistan Engineering Congress, October, 1963), pp. 1-14, at p. 9.

Lining of main and branch canals will reduce seepage, but most of this occurs from the smaller channels which are hardly ever lined or from the fields which cannot yet be sealed on more than an experimental scale. In every lined surface-water distribution system known to the present author, sealing has been provided only where economic calculations indicated that the value of water lost by seepage, especially in crossing areas of more permeable soils, exceeded the cost of the lining. Canals, like rivers, will eventually, though incompletely and intermittently, seal their beds with silt and clay materials, and there is accordingly a great temptation to rely upon this fact.

tion, but only where the cost is economically justifiable.

In irrigated area the growth of non-cultivated vegetation is unintentionally fostered along with that of crops. Where these "weeds" interfere with canal operation, impede cultivation, or consume an inordinate amount of water, efforts are made to remove them, but again only where economic returns outweigh costs. Some of this non-cultivated vegetation may actually have economic value where it stabilizes canal banks, provides fuel or building material, or transpires groundwater which would otherwise interfere with crop growth. Trees, of course, are especially useful in these respects and also provide welcome relief from heat and glare in villages, fields, and along roads which often parallel the canals. In most cultures, esthetic values are associated with the green landscape of irrigated areas, whether or not the plants have economic value. Some micro-climatic effects are induced by this vegetation as well as by the increase in evaporation mentioned above.

Although the irrigated landscape provides a generally hospitable environment for man, not only supporting him with food and water, shade and wood for fuel and building, but also usually enabling him to produce a crop surplus for trade. It has also brought menaces to life and health. Not the least of these, when seen in perspective, may be the support of a burgeoning population both within and outside the irrigation command. In those areas where the irrigated agricultural base is stable or actually shrinking, or where its further expansion cannot keep up with the demand for food, the long-term contribution may be seriously questioned. We shall return to this question in our analysis of the Punjam "granary," but here we must note certain local and more immediate menaces associated with irrigation.

All irrigation systems serve to increase the amount of standing water in proximity to villages and work areas. Thus, within the climatic parameters of the vectors, irrigation has generally increased the prevalence of waterborne or water-supported diseases, especially malaria and schistosomiasis. One should not overly blame the irrigator for these effects, which are unintended, and unwanted; at the same time, these side effects cannot be ignored.

II.

The present author has had the opportunity of doing field research in the oldest and the newest of the modern,[5] large-scale surface-water irrigation systems in Southwest Asia, those of the Indus Basin in West Pakistan and northern India, and of the Helmand Valley in Afghanistan. Although both systems had predecessors in nonperennial inundation canals; almost a century separates the completion of the perennial Upper Bari Doab Canal in the Punjab (1859) from that of the Bogra Canal in the Helmand Valley (1950). Within this period were constructed the modern, barrage-controlled perennial systems in Egypt, Mesopotamia, and Russian-Soviet Central Asia. Although there was considerable transfer of engineering knowledge and design theory among these projects, there is no evidence that anyone really learned from, or paid attention to, experience with waterlogging and salinity, even within the same political jurisdiction.

In the Indus Basin, several factors delayed recognition of such problems. The British were primarily concerned with extending the area under irrigation, bringing new lands - especially

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[5] "Modern" is here defined in technological terms to mean surface-water schemes employing the advances of the Industrial Revolution: (a) cemented masonry giving place to reinforced concrete; (b) cast-iron and then steel sluice gates; (c) overhead controls for barrage gates; (d) earth-moving machinery; and (e) hydraulic flow theory on design and operation. All of these, of course, made possible operations on a scale not previously imagineable.

Crown Waste Lands - into cultivation so that they could be settled and taxed. Ancillary motives including resettlement of discharged soldiers, relief of crowded conditions in long-settled areas, the creation of a Punjab Granary which could supply a grain surplus to famine-prone areas of north-central India, and later, especially in Sind, creation of new areas of cotton production. All of these motives combined with a cropping pattern dominated by wheat and cotton to allow the water to be spread thin. For these crops, which have low water requirements to begin with, water allowances were typically one-third to one-half what they would be in the United States,[6] and although sugarcane was allowed on limited acreages, rice cultivation was generally discouraged in the <u>doab</u> (interfluve) irrigation commands until watertables had risen close to the surface. Thus, although one can find references to waterlogging and salinity problems close to the Western Jumna Canal of the Ganges Basin as early as 1859,[7] and although the irrigation channels were realigned and natural drainages cleared in that command between 1870 and 1880 with gratifying results,[8] there was only scattered recognition of the general problem until 1925 when a Waterlogging Enquiry Committee was established. Even then,

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[6] White House-Department of Interior Panel on Waterlogging and Salinity in West Pakistan, <u>Report on Land and Water Development in the Indus Plain</u> (Washington, D.C., The White House, January, 1964), pp. 185 ff. and Appendix A.5.

[7] Aloys A. Michel, <u>The Indus Rivers</u> (New Haven, Yale University Press, 1967), p. 455.

[8] A.M.R. Montagu, "Presidential Address to the Punjab Engineering Congress, 33rd Session, 1946," in <u>Proceedings of the Punjab Engineering Congress</u>, 33rd Session, Lahore, 1946, pp. i-xvii, at pp. xii-xiii, cited in Michel, <u>Indus Rivers</u>, pp. 456-57.

and despite the fact that the Lower Chenab Canal, opened in 1892, had produced serious waterlogging by 1908, there were those who maintained that irrigation per se was not to blame but rather that the canal, road, and railway embankments were interfering with surface runoff and/or that the Punjab was in a "rainy cycle." Thus, although the Irrigation Branch of the Punjab Public Works Department was pfficially concerned with the problem by 1925, it too had its "anti-drainage lobby." The lure of adding new acreage was still strong, and few were interested in reclamation when lost acreage could be replaced elsewhere. Of course, the cost of bringing water to new acreage was increasing, and the new acres, whether in Sind or in the Thal Project between the Indus and the Jhelum-Chenab, had much coarser soils with lower initial fertility than those in the Punjab. In the desert areas to the west and south, both seepage and evaporation rates were higher, and even the Indus Basin would eventually run out of new lands to replace the old in a gravity-fed surface water irrigation system.

Despite these shortcomings it must be recognized that in 1947 the British left the Indus Basin with the most extensive and probably the least costly (on a per acre basis of commanded cultivable land) integrated irrigation system on earth. Partition destroyed the integration, but Pakistan did inherit the Sukkur and Thal Projects, both of which had (and still do have) a great deal of commanded cultivable area waiting to be settled, while India inherited the Bhakra dam site on the Sutlej which would allow her to emtend irrigation into Rajasthan.

1947 was also a key year in the development of modern irrigation in Afghanistan, marking the transfer of the Helmand Valley Project (see Map 2) from the Ministry of Public Works to the Morrison-Knudsen Company, an American firm which could bring to bear modern design and technology, in the form of heavy earthmoving equipment, rock-fill dams, and reinforced concrete barrages and canal structures. It is noteworthy that the need to employ the contractor, the designs, and the technology stemmed directly from a decision to extend irrigation from the Helmand floodplain areas - long irrigated with inundation canals - to the terraces west of the river which represented "virgin" lands.[9] It is also noteworthy that the employment of this modern technology, at least as represented by a foreign, private contractor, led to a further increase in the scale of the project, for Morrison-Knudsen quickly pointed out: (a) that a storage dam would be necessary if the irrigation needs of the terrace areas were to be supplied without detracting from the uses of the floodplain areas, and (b) that it would not be economical for Morrison-Knudsen to operate in the Helmand Project unless a spending level of at least $4 million per year could be maintained.[10] Also relevant to the decision to enlarge the scope of the Helmand Project to include the new lands west of the river were the Afghan Government's desire (1) to provide

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[9] Aloys A. Michel, The Kabul, Kunduz, and Helmand Valleys and the National Economy of Afghanistan (Washington, D.C., National Academy of Sciences - National Research Council, 1959), p. 149.

[10] Ibid., pp. 153-54.

areas for settlement of Pushtun nomads whose annual migrations to and from the Indus Plains began to be curtailed as a result of Pakistan's independence in August, 1947, and the ensuing dispute over "Pushtunistan," and (2) to obtain storage control of the Helmand and maximum use of its waters within the country in view of the dispute with Iran over allocation of flows in the river's inland delta region, the Chakansur Basin, which is transected by the border.

Thus, a variety of engineering, economic, and political reasons - to which may be added the usual considerations of professional optimism and personal/national prestige - led to the enlargement of the Helmand Project to include two storage dams (Kajakai and Arghandab), a supposed potential of a quarter of a million acres of virgin or abandoned land on the terraces west of the river (Nad-i-Ali and Marja project areas) or on the interfluves between the Helmand and its Arghandab tributary (Seraj area) and between the Tarnak and Arghastan subtributaries (Tarnak project area), and additional areas on the flood-plains (Shamalan, Darweshan, Garmsel, etc.)

It is essential to distinguish the Central Arghandab project area between the Arghandab and the Tarbak rivers from the rest of the rest of the Helmand Project. In this area, inundation canals had provided nonperennial irrigation for hundreds of years to permeable soils with little evidence of waterlogging or salinity. Here the object of the Halmand Project was to make available an assured supply of water which would allow perennial irrigation of most of the acreage. The Central Arghandab area, focused on Kandahar, is one of Afghanistan's primary sources of winter wheat, vegetables and deciduous fruit, with much of the latter exported, fresh or dried, to Pakistan and India. Here, the Helmand Project has been an undoubted success, doubling production and exports in good years and producing little evidence thus far of waterlogging or salinity though drains will eventually be required. The success in this area of "reinforced" agricultural production with good natural drainage is usually overlooked in assessments of the Helmand Project as a whole.

Also requiring separate treatment are the floodplain areas (Kajakai to Girishk, Shamalan, and Darweshan) where the project has brought increased supplies of water and an increase in annual cropped acreage to areas which had long been cultivated on a migrating inundation basis and which, due to the high natural watertable, showed signs of waterlogging and intermittent salinity long before the advent of the Project. Despite the construction of the two dams, control of runoff is far from complete. The storage provided can assure minimum flows but cannot prevent maximum flood runoff. And there is no control at all on the Arghastan and Tarnak rivers. Thus, the level of the watertables in the floodplains, especially in the active portions, depends primarily upon the fluctuations in the river levels, and while artificial irrigation certainly exacerbates waterlogging and salinity, restriction of surface-water supplies or even installation of gravity drains cannot, per se, reduce or eliminate the problem in flood years. Irrigation of these floodplains, as of most active and some inactive floodplains, has always been precarious. Where, as along the Helmand, the river banks ("natural levees") are generally the highest points on the floodplain, the danger of flood damage is extreme, as is the difficulty of building and operating any type of gravity drain. The Helmand Project, by providing fixed and regulable intake structures capable of withstanding most floods, and by providing gravity drains in those areas of the inactive floodplain where they will work when the watertable is low, has decreased the uncertainty for cultivators and can be justified on the same grounds as the nonperennial canals built by the British and Pakistanis along the Lower Indus and Sutlej. On the one hand, they are cheap to construct and guarantee a minimum supply of water, and on the other, the effect of irrigation water seeping to the watertable is minor in comparison with the natural fluctuations due to flooding or lateral seepage from the river itself.

This last factor is manifestly not true on the interfluves, and it was the extension of irrigation onto the terraces, notably in the Nad-i-Ali and Marja areas, that produced the serious and foreseeable problems which have given the Helmand Project its bad reputation in and outside Afghanistan. For here were conglomerate substratae through which irrigation water could not penetrate and which produced a 16-foot rise in the watertable within three or four years of the opening of the Boghra Canal in the spring of 1949. The rapidity of the rise was due both to seepage from unlined reaches of the canal and to excessive application of water by settlers unaccustomed to such an abundance, but the fundamental cause was the substratum which created a local base level. The incredible part of this story is that the existence, though not the extent, of these conglomerate layers was known to the Afghans, from their experience in constructing the predecessor of the Boghra Canal and to the contractors, from reconnaissance surveys.

But once again, optimism and short-sighted mess precluded a detailed survey until after the damage had been done. Afghanistan was left with over 40,000 acres of canal-commanded land on the terraces but no prospects for cultivating it in wheat or cotton, as had been originally planned until drains had been installed and a long program of reclamation, including the use of mechanical cultivation for salt-tolerant fodder crops and grasses, carried through. For reasons of policy and prestige, much of the burden of reclamation has been assumed by the U.S. Agency for International Development which has had Bureau of Reclamation teams working in the area for the past ten years, but it will be several more decades before the original promise of the Helmand Project in the terrace areas begins to be fulfilled.

What lessons have been learned from the Helmand experience? Unfortunately, none that could not have been learned without it! Irrigation experience in the adjoining Indus Basin, in Soviet

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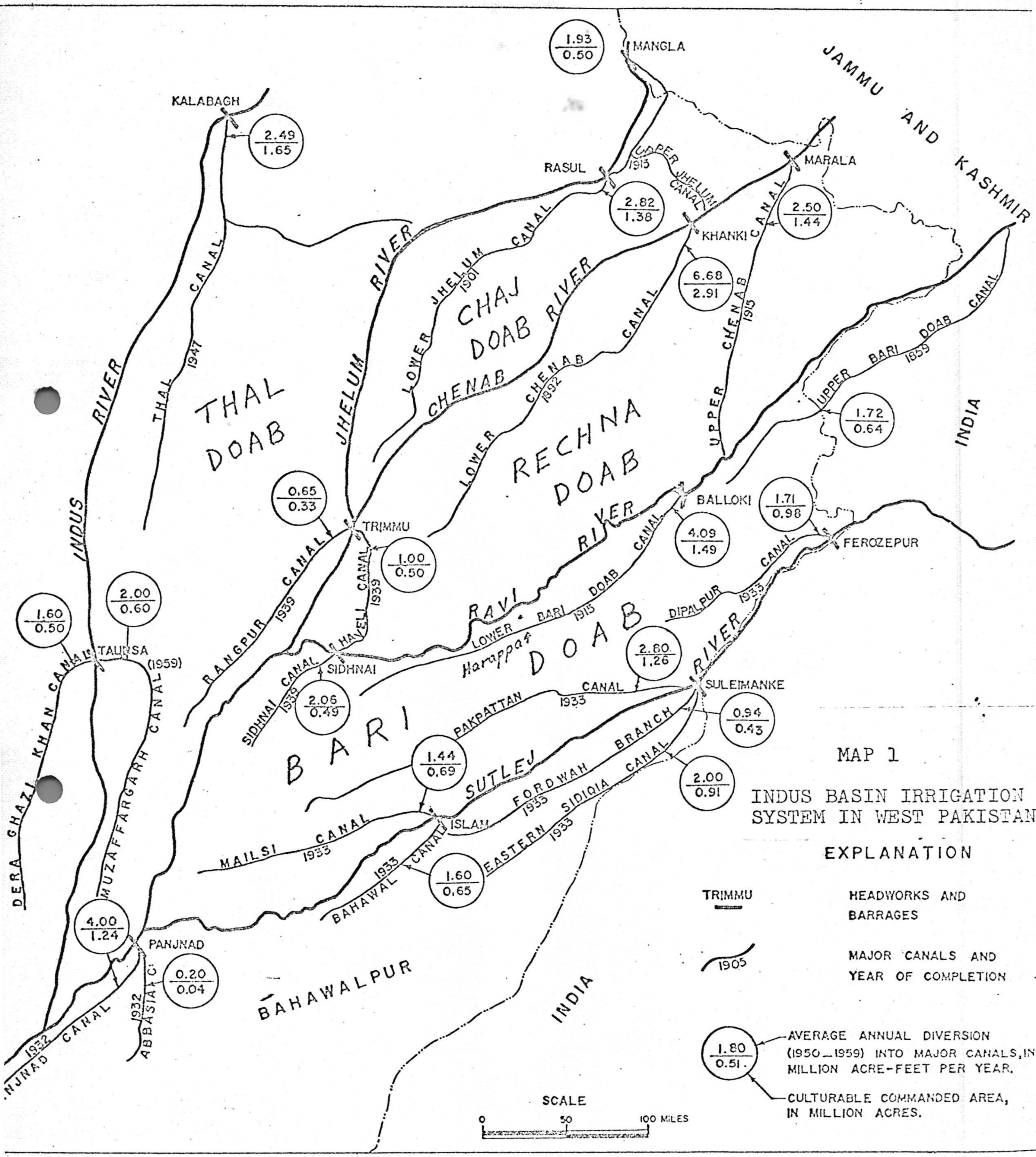
[11]Michel, Kabul, Kunduz and Helmand, pp. 152-53

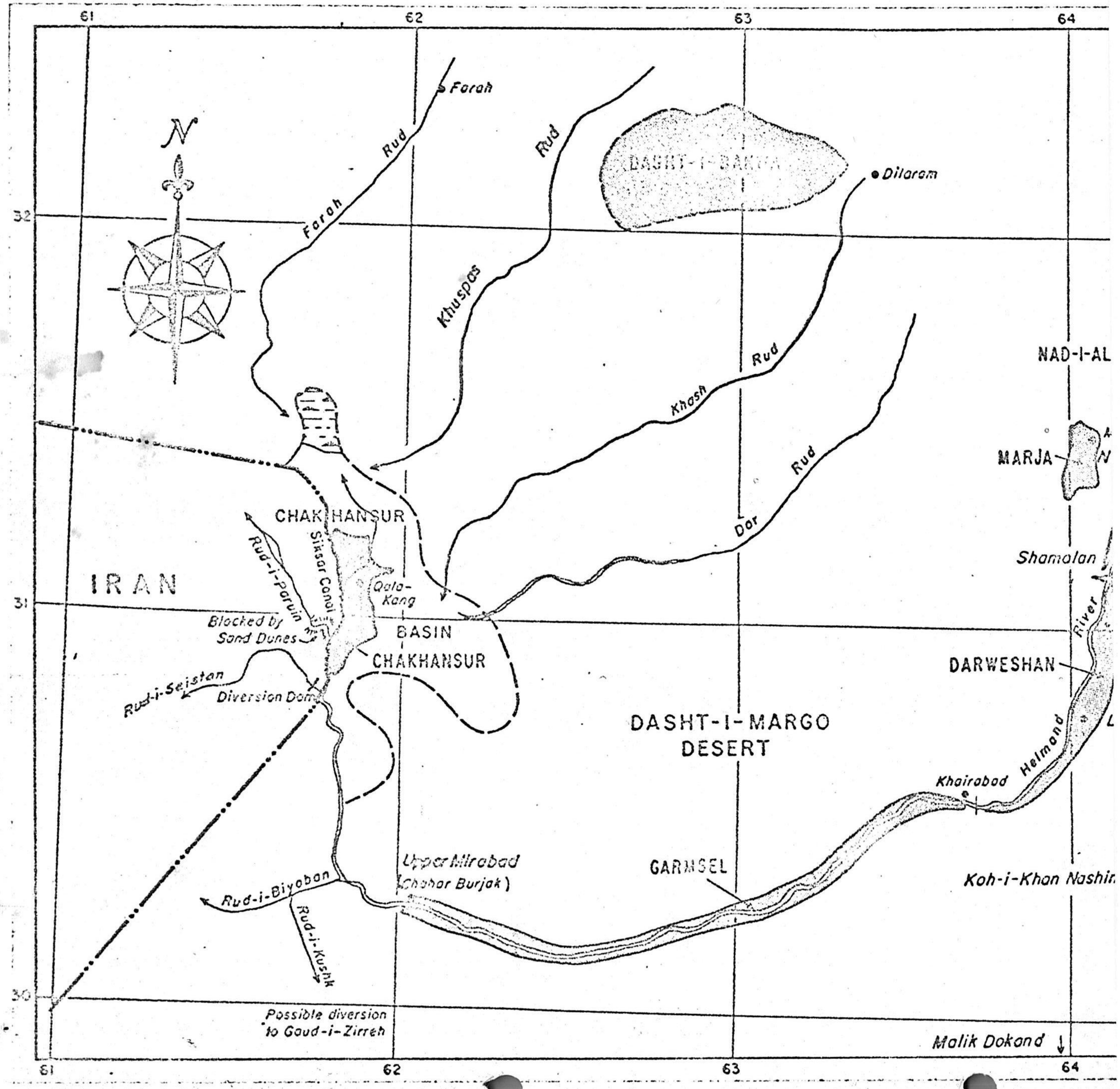
Central Asia, and in the southwestern U.S.A. all had shown that drainage must go hand-in-hand with irrigation. The only remarkable points in the Helmand experience are that disaster struck so quickly and that the reasons for it were so obvious. Any engineer or planner should have seen them from the design stage, and some did.[12] But instead of redesigning the project to exclude Nad-i-Ali and Marja, or substantially increasing the size of the holdings, or lowering the water allowances from the start, the project was implemented squarely in defiance of reality. In view of what we have said about the normal time lag associated with waterlogging and salinity, there is an ironic justice in the fact that nature struck back at those who ignored her before they could move on to other positions and to other projects. But the saddest thing about the Helmand experience is that it will probably be repeated, if not in Afghanistan, then in Iran or Iraq, though it may be difficult to find soils as poor as those of Nad-i-Ali and Marja. It is also unfortunate that the nature of the Helmand terrace soils, because of the very shallow depth to impermeable substrata and the consequent lack of both "freeboard" and underlying fresh groundwater supplies, would seem to preclude the type of tubwell reclamation now being employed in the Indus Basin of West Pakistan, which is the subject of the next section of this paper.

12 <u>Ibid</u>.



MAP 1

INDUS BASIN IRRIGATION SYSTEM IN WEST PAKISTAN



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Rud-i-Parwin
Qala-Kang
BASIN
CHAKHANSUR
IRAN
Blocked by Sand Dunes
Rud-i-Seistan
Diversion Dam
DASHT-I-MARGO DESERT
Shamalan
DARWESHAN
Helmand River
Khairabad
GARMSEL
Koh-i-Khan Nashir
Upper Mirabad (Chahar Burjak)
Rud-i-Biyaban
Rud-i-Kushk
Possible diversion to Goud-i-Zirreh
Malik Dokand

The Helmand experience is typical only in that it represents a microcosm of what has been going on in other surface-water irrigation projects over longer periods of time. For our purposes, the Indus experience is more typical and perhaps more hopeful. As we have seen, many of the British engineers and administrators recognized the problem at least 40 years ago, and some of them tried to do something about it. Aside from the policy of speading the water thin, which had always carried an economic rationale, canals were realigned, some of them were lined in badly-leaking places, and surface drains were constructed. These policies, including the low water allocations, were continued by the Indians and Pakistanis after Independence. But the most promising attack on the problem was proposed as early as 1927 though not approved until 1944 and not put into full operation until 1952, five years after Independence. This was the Rasul Scheme in the Rechna and Chaj Doabs of West Pakistan which employed 1257 tubewells ranged along badly-seeping canals in a dual effort to lower local watertables and also make available additional supplies of irrigation water. Because most of its wells were too close to the canals and actually accelerated seepage, the Rasul Scheme was not particularly successful,[13] but its shortcomings led to further research and experiments and to the massive "Program for Waterlogging and Salinity Control in the Irrigated Areas of West Pakistan" initiated by the West Pakistan Water and Power Development Authority (WAPDA) in 1961.

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13 Michel, Indus Rivers, pp. 458-60.

In the meantime, firmer and more alarming evidence on the extent of the deterioration had become available. Air photo analysis qualified by field observations and laboratory tests indicated that of the 23 million acres annually canal-irrigated and sown to at least one crop, 5 million had been seriously damaged by waterlogging or salinity and between 50,000 and 100,000 additional acres were being affected each year, many of them passing out of crop production altogether. In the worst districts, located in Rechna Doab, 40 or 50 per cent of the cultivated land had been severely damaged.[14]

Historical data on the rise of the watertable showed average rates of from 0.6 to 1.0 feet per year since modern irrigation facilities had been provided in areas underlain by thousands of feet of virtually unobstructed alluviums.

> in an area where the underground water has a salinity of 1,000 parts per million /acceptable for virtually all crops/ evaporation at a rate of 2 feet per year (a typical value when the water table is only a few feet deep) will raise the salt content of the top 3 feet of soil to about 1 percent in 20 years. This is too high for even the hardiest crops.[15]

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[14] White House-Interior Panel Report, p. 57. Salinity defined as "the areas in which white efflorescence is apparent on the natural surface during the months of December, January, or February, causing 1/5 or more damage to the crop of the area," caused 97 percent of the damage.

[15] <u>Ibid</u>., p. 56. Ibid., fn. 29

The response of the farmer to the alarming increase in waterlogging and salinity in the irrigated districts of the Pakistan Punjab has been twofold. Where the watertable is at or very near the surface, he usually shifts from wheat to rice cultivation. Although the West Pakistani is traditionally a wheat consumer, rice is a fairly salt-tolerant crop which thrives on a high watertable. It yields more calories per acre than wheat and can be exported, either to East Pakistan or abroad, and the money received can be used to purchase Food for Peace wheat which is sent almost exclusively to the West Wing of Pakistan. Thus between 1949-50 and 1959-60 the acreage sown to rice in West Pakistan increased over 30 per cent, from 2.3 to 3 million acres, and the yield per acre increased from 773 to 823 pounds. Over the same period, wheat acreage increased only from 10.3 million acres to 12.1 million, while the wheat yield per acre actually fell from 839 to 724 pounds.[16]

The usual response in irrigated areas affected by salinity rather than by waterlogging has been to try to delay the process by sowing only one crop per year or to spread the available irrigation water even more thinly over the saline land. Although the gross sown area in the Punjab districts with major canal irrigation systems increased about 1.5 per cent per year over the period 1949-50 to 1958-59, the White House-Interior Panel reported: "In the older canal systems, the increase in gross area almost certainly means that the volume of irrigation water correspondingly decreased."[17] Such a response will ultimately make

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[16] Government of Pakistan, Central Statistical Office, Statistical Pocket-Book of Pakistan, 1964 (Karachi: Manager of Publications, 1964), Table No. 12, pp. 78-79.

[17] White House-Interior Panel Report, p. 45.

the problem worse as salts accumulate in soils that never get enough water to leach the salt below the capillary zone, let alone below the root zone. As we have seen, the combination of capillary rise and evaporation will simply return the salts to the surface where they will accumulate until the land must be abandoned.

Nor can new lands be brought into cultivation fast enough to offset the decline of the old. For all of West Pakistan, the increase in gross sown area over the period 1949-50 to 1958-59 was only 1.3 per cent per annum, or less than that in the Punjab alone. The overall population increase for West Pakistan between the 1951 and 1961 censuses amounted to 2.4 per cent per annum (2.2 per cent per annum in the canal-irrigated districts of the Pakistan Punjab). What these figures mean in summary is that despite the introduction of new irrigated lands neither in West Pakistan as a whole nor in the old "Punjab Granary" is the increase in gross sown area keeping pace with population increase. The sad historical fact is that, dueto population increase, the Punjab Granary had ceased to provide any substantial grain exports beyond its borders by the time of Partition, and that although West Pakistan inherited virtually all of the surplus-producing irrigated areas, population increase combined with waterlogging and salinity damage quickly overcame this initial advantage and made the country a net importer of wheat by the mid-1950s.

Even apart from per capita considerations, it was apparent by the mid-1950s that a shortage of surface water for crop and soil-leaching requirements was combining with loss of acreage and decreasing yields due to waterlogging and salinity in a vicious circle which had somehow to be broken. So while the Pakistani nego-

(page 23. follows)

tiators were working (1952-60) with their Indian counterparts and the World Bank to devise surface-water replacement and enhancement possibilities, including storage dams, other technicians were looking below the surface. As we have seen, the Rasul Scheme indicated the possibility of using tubewells in a two-pronged attack on the problem: to lower watertables and at the same time to provide additional supplies for irrigation and leaching. In 1953-54, a second Rasul-type scheme was inaugurated by Pakistani and F.A.O. technicians near Chuharkana in the Rechna Doab, and in 1957-58 a third pilot project was started near Jaranwala in Central Rechna. Under the U.S. Point Four Program, a team of U.S.G.S. experts arrived in 1954 to work with the Punjab Irrigation Department's Soil Reclamation Board (1952) amd Ground Water Development Organisation (1954) on surveys and analysis. When the West Pakistan WAPDA was established in 1958, it was specifically entrusted with "prevention of waterlogging and salinity and reclamation of waterlogged and saline lands."[18]

From these antecedents developed WAPDA's Salinity Control and Reclamation Project Number One (SCARP I) including nearly 2000 tubewells installed in the Rechna Doab and WAPDA's ongoing program to complete some 9000 tubeweels by 1972. But the key to the program, and the factor which differentiates it from its predecessors, lies in the concentration of these tubewells in fields (SCARPS I to IV) of from 1500 to 3000 tubewells, each of 3 or 4 cusecs capacity, and each serving approximately 600 acres. The capacity and spacing of

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[18] Michel, Indus Rivers, pp. 463-67. An excellent description and analysis of the groundwater program in West Pakistan has been furnished by the former Chief of Party of the U.S.G.S. Ground Water Group. See David W. Greenman, "Hydrology and Scientific Reclamation in the Punjab, West Pakistan," in Richard J. Ward, ed., The Challenge of Development (Chicago: Aldine, 1967), pp. 173-182.

the wells is designed to permit man to "dominate the drainage," within each project area. By 1975 the program may be extended to include some 20,000 wells and an area of 12 million acres, virtually all of which would lie within the existing commands of the surface water system in the Punjab, Khairpur and Sind regions of West Pakistan. Combined with supplies from an even greater number of privately-owned 1-cusec wells and the enhanced surface-water supplies made possible by the Mangla and Tarbela dams on the Jhelum and Indus Rivers, respectively, the amount of water available for watercourse delivery in West Pakistan may reach 93.5 million acre feet in 1975. Two-thirds of this supply would come from the surface-water storage and distribution system and almost one-fourth from the government-owned tubewells. The total supply represents a net addition of about 38 per cent of the 68 million acre feet available in 1965 and thus will offer a substantial improvement over the traditional low supplies available to crops and for leaching of salts from the topsoil.

But this increase in the amount of water spread on the surface would serve only to increase the waterlogging and salinity damage to soils and crops were it not that the massive concentrations of high-capacity tubewells offer the hope of controlling the level of the watertable. Wherever the groundwater is of usable quality (roughly, 2000 parts per million of total dissolved solids or less, depending upon the chemical quality of the salts) its use for crops should produce a net gain and, through consumptive use and evapotranspiration, result in a gradual lowering of the watertable. In other areas, saline groundwater will have to be mixed with surface water of good quality before being applied to crops. To accomplish this mixing, canal capacities in certain areas will have to be enlarged. In still other portions of the areas selected for initial development, the groundwater is too saline even for blending and will have to be exported either via the rivers or via new wasteways constructed for the purpose.

Thus the groundwater and reclamation program underway in West Pakistan represents an extremely complet and costly effort to offset the consequences of surface-water irrigation. For the periods of Pakistan's Third and Fourth Five Year Plans (1965-75), the total cost of government-owned tubewells, canal remodelling and drainage works (not including surface-water storage) will amount to 5.3 billion Pakistan Rupees, or $1.1 billion at official exchange rates, or slightly more than the cost of the Tarbela dam, which itself represents roughly half of the total cost of the Indus Basin Project. The expectation is that the gains achieved in West Pakistan's agricultural sector, which has been growing at a healthy rate of 3 to 4 per cent per annum since 1960, will eventually more than compensate for these investments. But these gains will depend not only upon increased surface- and groundwater supplies but upon further inputs of fertilizers, improved seed varieties, insecticides & pesticides and upon improved cultivation techniques, discussion of which is beyond the scope of this paper.[19]

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[19] The interested reader is referred to the White House-Interior Panel Report and to Michel, <u>Indus Rivers</u>, chs. 8-10.

Do man's experience and expectations in the Indus Basin mean that he is about to achieve mastery over his environment in irrigation agriculture? Such a boast would smack of <u>hubris</u>, for nature undoubtedly holds unpleasant surprises in store for him. Some of these turned up in the initial years of the tube-well program in the Punjab, where the obsolescence rates in portions of SCARP I were so alarming that by mid-1964 installation of wells in SCARP II was halted until the trouble could be diagnosed. The problem was found to be a combination of mechanical blocking and chemical corrosion of the mild-steel strainers (filter screens used to exclude sand and gravel from the wells), abetted by the work of sulphate-reducing bacteria present in the groundwater or introduced in drilling the well. The remedy seems to lie in use of fiberglass strainers (which by 1967 were less expensive and easier to install than the steel ones) combined with chemical solutions to initially sterilize and later occasionally clean the wells. But one would be foolhardy to conclude that similar problems will not arise in the future.

Indeed, two more problems are already emerging:

(1) What can ultimately be done with the salts which keep on accumulating down-doab and downstream? The completion of Tarbela Dam in 1974 or 1975 will raise the mean annual diversions of good quality surface water in West Pakistan to the order of 92 million acre-feet. This supply can be supplemented for 20 or 30 years by "mining" the enormous reservoir of perhaps 2 billion acre-feet of

good quality groundwater underlying the Punjab. After the year 2000, mining would have to be tapered off, but use could continue of perhaps 20 million acre-feet per year of groundwater recharge in the Punjab. But sooner or later the concentration of salts, due to repeated capillary rise and evaporation followed by repeated irrigation and leaching, is bound to increase both down-doab and downstream. Sind is already alarmed both because the salt content of water in the Lower Indus is slightly higher than in the Upper Indus and its Punjab tributaries and because the reservoir of good quality groundwater in Sind appears to be far smaller than that underlying the Punjab (though it might yield as much as 12 million acre-feet per year). Actually, the principle justification for building Tarbela Dam, aside from its hydroelectric potential, is to assure Sind of firm supplies of good quality water below the confluence of the Punjab tributaries. But Sind lies with respect to the Punjab in much the same position as Mexico with respect to the United States on the Rio Grande or the Colorado, and it seems inescapable that the Lower Indus must serve as the "sink" of the whole Indus system, whether in Afghanistan, West Pakistan, or India.[20] If anything is "natural" it is that water flows downhill - and that it carries dissolved salts with it. Of course, it is feasible to "export" highly salinized water either directly to the ocean or into "sinks" along the desert

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[20] It is not entirely clear from the Indus Waters Treaty of 1960 that India cannot use the beds of the Eastern rivers as drains. The question hinges on the definition of "pollution." If discharge (whether surface or subsurface) of saline irrigation effluent constitutes "pollution" then the Treaty forbids it. If not, then West Pakistan and especially Sind may just have to suffer the consequences. Failure to consider these consequences in detail in writing the treaty is another example of the optimism and procrastination noted in Section II of this paper. (See Michel, Indus Rivers, p. 338.)

margins, but the costs involved imply that the wasteways required are a long way off and prone to being postponed while other elements are constructed.

(2) The second problem is more human than "natural," though what is more "natural" than human nature? It is the problem of operating and maintaining so vast and complex a system as that contemplated for the Indus Basin in Pakistan. It has been suggested that because of the time factor the large-scale irrigation systems of the last hundred years could not have been worked without the telegraph. It now appears that those of the next hundred years can be worked only with the computer. This will certainly be true in West Pakistan where man is attempting to control all four dimensions and to manipulate the groundwater reservoir as well as the surface flows. Fortunately, analog computers may easily be programmed to simulate groundwater pumping recharge and flows,[21] and one can already imagine WAPDA House in Lahore being converted (over the protests of the Irrigation Department) into a command post flashing signals to hundreds of gate and pump tenders - or indeed to thousands of automated valves, gates and pumps - to keep the system operating so as to maximize whatever goals are set. What is not so easy to imaging in a land where preventive maintenance is still only a slogan is an efficient and skilled army of mechanics and electricians repairing the breakdowns or, preferably, replacing valves, pumps and well-screens upon signals from automated monitors before they break down. But this too will have to come. It is also hard to see, at this time, where Pakistan will get the money not only for the groundwater and reclamation program/but for the

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[21] David K. Todd, "Advanges in Techniques of Ground Water Resources Development," in Ward, Challenge of Development, pp. 160-171.

overall agricultural development program needed to make it pay.

But a realistic awareness that problems foreseen and unforeseen are bound to arise - they always do - should not prevent us from looking ahead to what the new irrigation technology might bring to pass in the Indus Basin and in analogous irrigation systems elsewhere. Acceptance of the fact that irrigation and drainage are inseparable components of a single system has advantages once the tubewell is employed as the instrument for controlling the watertable. Wherever the groundwater is pure enough to be used, straight or mixed, for cropping, there is a windfall to be gained until such time as the watertable is below the economic reach of the pumps (and this economic reach will be lengthened as the efficienty of pump design increases, as power costs are lowered, particularly with nuclear-power plants, or as the relative value of crops rises). This windfall in groundwater irrigation may be compared to the initial advantage accruing to the cultivator of virgin lands who "draws down" the accumulated fertility for the first few years. When the cultivator has exhausted the initial fertility, he must find means of replacing it; so with the "miner" of the groundwater. Both will be aided somewhat by nature over time: the cultivator by fallowing or at least leaving stubble and roots to return nutrients to the soil; the groundwater irrigator by taking advantage of the natural recharge to the watertable. And both can employ "artificial means" to recharge their elements: the cultivator with green manures and manufactures fertilizers; the groundwater irrigator by aiding nature through artificial recharge of thegroundwater. The latter of course requires surface water to be infiltrated, but here again the factor of canal seepage can be turned to good account as the largest element in groundwater recharge, aided by the ponding which is necessary to reclaim saline soils or by excess ponding during fallow periods, or even by employing recharge wells. Such use of the groundwater reservoir eliminates the evaporation problem, converts stream-bed and canal and field seepage into advantages, and may even curtail the need for additional surface storage (with its accompanying disadvantages of evaporation from and sedimentation into the reservoirs). This last is a particularly important problem in West Pakistan where good surface storage sites are few and dam construction costs accordingly high.[22]

Once a groundwater reclamation and development program has been thoroughly integrated into a massive surface-water irrigation scheme it may be hard to recognize the "natural system." The White House-Interior Panel envisages the day, circa 2000 A.D., when of the 136 million acre-feet entering West Pakistan in the Indus Basin in a mean year only 10 per cent or 13.8 million acre-feet will reach the sea, and 106 million acre-feet of surface and groundwater will be available for crops, permitting a water allowance of at least 4 acre-feet per acre of the 23 million now canal-irrigated. Whether this will be achieved depends on all the economic and physical factors enumerated in this paper, plus others which none of us has yet taken into consideration. But as far as we know, the technological means appear to be at hand, and in an impressive

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[22] For an excellent presentation of the advantages, and the problems, of such an integrated system in West Pakistan, see Greenman, loc. cit., pp. 177-182.

[23] White House-Interior Report, pp. 283-88. This does not imply that the water should be so distributed. In fact the Panel cogently argues that it should be concentrated on a substantially smaller area.

array. Man has already changed the natural system of the Indus Basin to the point where only 40 per cent of the natural flow reaches the sea. If, by the end of this century, he succeeds in reducing it to 7 per cent, he should at least be entitled to ask the question, "Does water really flow downhill?"

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With rare exceptions the surface water irrigator has been rewarded with immediate and often spectacular results. These results stem from the fact that he is introducing a new element--water in large, assured, and more or less controlled quantities--into environments which are naturally arid or semi-arid. In the vast majority of cases, he gains the initial advantages of plant nutrients built up over centuries or millenia and, providing he is neither blind nor stupid, of a low groundwater table. But both of these initial assets are depletable, sometimes shockingly so. The nutrients, especially the nitrates, are quickly used by plants or carried beyond their reach by the water he supplies to make the desert bloom. And the water which seeps into the subsoil usually accumulates until it becomes a menace to continued cropping either directly or by contributing through capillary rise and evaporation to the accumulation of salts in the topsoil.

(page 33 follows)

There would seem to be a valid parallel between the efforts of the irrigator and those of the sodbuster. Both approach their environments with good will and earnest determination to improve their own lot and, indirectly, that of their fellow man. Both set out to improve upon nature and, initially, both usually succeed. But each is opening a Pandora's Box and often derives results which he neither intends nor desires. The irrigator is eventually beset with declining fertility, waterlogging and salinity; the sodbuster with gullying or soil blowing.

What amazes me in the history of agriculture is that the lessons of field cropping in the semiarid margins have to be learned again and again, from place to place and from time to time. The Soviets, in their famous Virgin and Idle Lands program, ignored not only the U.S. experience in the Dust Bowl but the experience of their own forebears who abandoned the "idle" lands less than a century ago. We now have good reason to believe that the decline of the ancient irrigated civilizations of Mesopotamia and Central Asia was due not to climatic change or to Attila the Hun, but to soil depletion, waterlogging and salinity. The distribution system of the Lower Bari Doab Canal in the Punjab (see Map 1) encompasses the site of ancient Harappa, whose ruined granaries testify to the existence of an extensive irrigation-based civilization 4000 years ago. Although air photo analysis now confirms earlier suggestions that the Ravi River has moved a few miles away from the Harappa site, the unanswered question is, "Why did Harappa not move with it?" Nor is the downfall of Mohenjo Daro west of the Lower Indus fully explained by alien invasions or migrations of the Indus.[25] In both cases, some additional factor must have made it unrewarding to rebuild the irrigation system. Knowing what we now know about the cumulative effects of irrigation in inducing high watertables and surface salinity, we must ask: are these same fields about to pass out of production a second time for reasons of declining fertility, waterlogging and salinity? Is the irrigator still unable to cope with the consequences which his innovation inevitably introduces?

Many irrigation engineers have had the wisdom to recognize and the courage to state that provision of an artificial drainage system is an inescapable concomitant of providing an artificial irrigation system. But the time dimension of irrigation, noted above, usually acts to ensure that only the storage and distribution components are initially provided. Since the irrigation-induced rise of the watertable to a level where waterlogging and salinity seriously interfere with cropping normally requires a period of years, there is a strong temptation to postpone drainage works, even though all concerned recognize

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[24] Herbert Wilhelmy, Director of the Geographical Institute, University of Tubingen, Germany, has made a thorough study of the air-photo mosaics of West Pakistan and has published a number of articles on the results.

[25] The New York Times of November 20, 1968 (p. 3) suggests that it was flooding from the Indus which caused the abandonment of Mohenjo Daro around 1500 B.C. But the article goes on to note that the river is (? again working close to the site, causing a rise in the watertable and of salts, left behind by evaporation, in the ruins. The salts, by corroding the bricks, are threatening to destroy what is left of the ruins.

that the ultimate cost will be higher because it will entail disruption of the irrigation system and of agricultural production while surface (opencut) or subsurface (tile) drains are installed. Reinforcing this temptation is the fact that the construction costs of the storage and distribution works almost always exceed the estimates, so that even where drainage works are included in the original plans they are the first elements to be dropped or postponed as construction proceeds.

Human nature's ingrained optimism and tendency to procrastination make yielding to this temptation all the easier, as does the fact that the system designers are often driven to underestimate costs (or to include disposable items) in order to obtain administrative, legislative, or voter approval for their schemes on the proven theory that once ground is broken the project will have to be seen through to completion. Furthermore, the engineer, planner, contractor, bureaucrat, or politician may be looking for a short-term personal or professional gain. By the time the omission of a drainage system begins to damage crops, he usually has moved on to another project or another constituency, or has retired. These factors would seem to apply in all modern societies regardless of their ideological orientation. A recent article by I. P. Gerasimov, Director of the Institute of Geography in Moscow University, noted that:

> under the administrative pressure of the "anti-drainage lobby," no provision was made in the irrigation plans of the Golodnaya Steppe [southwest of Tashkent] for the construction of the required drainage structures, and calculations of water requirements and carrying capacity of the South Golodnaya Steppe Canal failed to provide for the additional water necessary to wash salt out of the soil. Water requirements for irrigation were based on minimal sprinkling norms.[26]

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[26] I. P. Gerasimov, "Basic Problems of the Transformation of Nature in Central Asia," from Problemy osvoyeniya pustyn', 1967, no. 5, pp. 3-17, in Soviet Geography IX no. 6 (June, 1966), pp. 444-58, at p. 448.

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