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Institutional Rationing of Canal Water in Northern India: Conflict between Traditional Patterns and Modern Needs*

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Irrigation has historically been especially important in India, with its monsoon climate. Along with the growing population pressure, the advent of the so-called green revolution has enhanced the importance of irrigation and heightened the need to use limited water resources with maximum effectiveness.[1] The system of rationing irrigation water directly affects the efficiency with which farmers can use water, and rationing used in large-scale canal irrigation is especially important because canal irrigation comprises a major component of the total Indian irrigation system.[2]

* This paper presents some of the results from the author's Ph.D. thesis, "Canal Irrigation and Institutions in North India: Microstudy and Evaluation" (Durham, N.C.: Duke University, 1971) directed by Joseph J. Spengler and based on research in India under a Fulbright-Hays fellowship. The paper was written under a post-doctoral appointment in Agricultural Economics and Water Science and Engineering at the University of California, Davis. Varden Fuller, Charles Moore, and Eric Gustafson provided helpful comments on earlier drafts of this paper. Responsibility for its shortcomings, however, lies with the author. The help and cooperation of the many active irrigation engineers interviewed in obtaining the largely unpublished data on the operation of the canal system are sincerely acknowledged, as are the contributions of the 168 farmers interviewed to obtain the necessary farm data.

[1] The Fourth Five Year Plan clearly recognizes this in stating that "the possibilities offered by the new seed varieties for increasing yields of cereal crops and intensifying cultivation are contingent on irrigation" (Planning Commission, *Fourth Five Year Plan* [New Delhi: Government of India, 1969], p. 245).

[2] At present, large-scale canals serve roughly 37 percent of the irrigated area in India. With 37.6 million hectares under irrigation in 1968, India has the largest amount of irrigated land in the world (with the possible exception of China) and more than double the irrigated area of the United States. The percentage of cultivated land receiving irrigation in India was roughly three times higher than that in the United States. Although tube-well irrigation is currently receiving strong emphasis, the future importance of large-scale canal irrigation seems assured. During the first three plans, canal-irrigation potential created or anticipated from projects under construction increased by 17.2 million hectares, compared to 7.3 million hectares for tube-well irrigation, the second largest category (see Directorate of Economics and Statistics, Ministry of Food, Agriculture, Community Development, and Cooperation, *India Agriculture in Brief*, 9th ed. [New Delhi: Government of India, 1968], p. 47; and K. K. Framji and I. K. Mahajan, *Irrigation and Drainage in the World: A Global Review*, 2d ed. [New Delhi: International Commission on Irrigation and Drainage, 1969], p. 420).

This paper examines the rationing system used with the Bhakra canals, one of the major new canal systems in north India, and focuses on a study area in Hissar District.[3] Rationing occurs at three principal levels: first, at higher levels, with the allocation of water available in the reservoir; second, at the middle level, with the rotation among channels of the preference to receive water; and third, at the farm level, with the rotation of turns among farmers (*warabandi*) served by the same watercourse,[4] which is the ditch from the main channel to the farmers' fields.[5] Institutional or administrative decision rules and schedules rather than market forces govern canal-water rationing.

The interaction of rationing at the various levels introduces a substantial degree of uncertainty in the farmers' water supply, in addition to a relative scarcity of water. This analysis will focus in detail on rationing and interaction at the two lower levels—the rotation among channels and the *warabandi*—that most directly affect farm water supply. Primarily consideration will be given to the winter season (*rabi*) when rainfall is negligible and irrigation most crucial. The effects of the rationing system may partially explain the often disappointing performance of many canal irrigation projects with respect to yields, profits, and utilization of irrigation potential.[6] These effects may also help explain the relatively sudden increase in private tube wells even in canal-irrigated areas, if cultivators find that their canal-water supply severely limits their ability to participate in the green revolution.[7]

[3] Hissar District is the largest district in the state of Haryana. The case-study area is approximately 100 miles northwest of Delhi. Rainfall is about 16 inches yearly, and the area depends heavily on irrigation, especially in the dry winter season. Bhakra canals come several hundred miles to serve the area. These canals are fed from the 8 million-acre-foot reservoir of the Bhakra Dam. For comparison, Shasta Dam, the keystone of California's Central Valley Project, has only about 4.5 million acre-feet of storage.

[4] In effect, the outlets from the main canals to the watercourses serving the cultivators' fields also ration the available water supply. These outlets have no gates for regulation. By their design, they automatically draw relatively less water from the main channel as its water level decreases, thus passing downstream a relatively larger proportion of the available water supply. This allows the tail reaches of the system to receive their share of the water even during low levels of flow in the main canal. In doing this, however, the outlets magnify the effect of canal-supply fluctuations on the water supply received by the cultivators.

[5] The channels of the system vary in size from the largest mainline canals to the smaller branches, subbranches, distributaries, and minors of very small capacity. A watercourse serving many individual farms may receive its water directly from any of these except the largest.

[6] As Nasim Ansari states: "Even in a region where irrigation has existed for long, agricultural development may remain quite restricted, hardly going beyond increased intensity of cropping and some changes in cropping patterns" (*The Economies of Irrigation Rates: A Study in Punjab and Uttar Pradesh* [New Delhi: Asia Publishing House, 1968], p. 170).

[7] A recent government report on the high-yielding varieties states that "a relatively larger proportion of plots under canals reported inadequate irrigation compared to plots under other sources," especially private tube wells (Programme Evaluation Organisation, Planning Commission, *Evaluation Study of the High Yielding Varieties*

In general, the rationing system will be evaluated in terms of its capability to supply water according to the needs of individual cultivators, and in particular, the predictability, certainty, and controllability of the timing and quantity of his water supply. Some data will be presented to indicate the canal-flow characteristics resulting from the operation of the system, but the evaluation is primarily qualitative due to the lack of necessary field data. For example, water supplied to individual farmers is not metered volumetrically. Nevertheless, a qualitative evaluation should help identify those elements of the system that most directly interfere with the predictability and usefulness of the cultivator's water supply, and thus those aspects most in need of alteration and additional research. Finally, several possible alterations will be suggested to improve predictability, certainty, and control of the cultivator's water supply with minimal change or disruption of the system.

Predictability, certainty, and control are relevant criteria for evaluating the cultivator's water supply. "There are important, fundamental agronomic reasons for delivering known amounts of water to fields. . . ."[8] The timing and quantity of water applied largely determine how much of that water will be captured for the consumptive use of the crop, rather than wasted. Control over timing and quantity of his water supply would enable the farmer to equate marginal revenues and costs from water applied, and to eliminate one source of risk in planning his farm operations. Even without water control, a highly predicatable and certain water supply would permit him to approach profit maximization with precise farm planning, and actual outcomes should closely match expectations. However, as the certainty of his water supply decreases, the farmer must reduce the level of all inputs, and thus output and profits, in order to decrease the chance of loss. Fertilizer, for example, is relatively costly, and the return from its use depends at least partly on the timing and quantity of water received by the crop. To ensure that the marginal returns from fertilizer at least equal its marginal cost, the farmer with an uncertain water supply should apply fertilizer at a relatively low level. Such risk adjustments sacrifice per acre output and profit for a higher probability of positive net returns.

A similar risk adjustment can also occur in water management, resulting in a water-application rate well below the economically optimum level in order to assure that marginal returns from water applied at least equal

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Programme: Report for Rabi 1968–69—Wheat, Paddy, and Jowar [New Delhi: Government of India, November 1969], p. xi). The response has been a surge of tube-well construction since the high-yielding varieties were first introduced. Since 1965–66 the number of tube wells has tripled, though the total number (400,000) is still relatively small (F. A. Ahmed, "New Dimensions of the Green Revolution," *India News* [Washington, D.C., Indian Embassy], January 22, 1971, p. 1).

[8] Chester Evans et al., *Need of and Plan for Research on Water Use and Soil Management toward Meeting India's Food Shortages*, report issued by the International Agricultural Development Service, U.S. Department of Agriculture; Agency for International Development, U.S. Department of State; and the Indian Council of Agricultural Research (New Delhi: Government of India, 1967), p. 20.

marginal cost, and certainly remain nonnegative.[9] Agronomic, climatic, and soil factors can, however, severely limit the possible reduction in water-application rates. The farmer may therefore diversify his crop pattern as an additional risk adjustment and include drought-resistant but low-valued crops, such as gram.[10] Wheat is generally more profitable than gram. Gram, however, is highly drought resistant, and is grown extensively in the area as a hedge against the uncertainty of the canal-water supply.[11] If available water exceeds what wheat can profitably use, the surplus can be applied to gram, which responds well to one or two irrigations. But if water is in short supply, the gram can generally produce a small profit without irrigation.[12]

[9] Because of low water costs, the profit-maximizing point will likely occur very close to the point where marginal product becomes negative on the farmer's production function for water. The marginal cost of water is primarily the labor for application, because the water levy is on a per acre rather than volumetric basis; that is, the farmer pays according to the number of acres he irrigates rather than the amount of water he uses. While the marginal cost of water is very low, it nevertheless has a high opportunity cost because of its scarcity. The farmer has insufficient water to irrigate all his land and cannot afford to waste the water, and he certainly does not want to apply so much that marginal product becomes negative. Figure 1 shows a production function for water and the reduction in output and input due to the risk of an uncertain water supply. It indicates the economically feasible region—stage 2—between the point of maximum average (AP_{max}) product and the point where marginal product becomes zero ($MP = 0$). Assume prices and returns such that marginal returns equal marginal costs at W_1 units of water applied, with a corresponding yield Y_1. To maximize profit, the farmer should plan his farm so that each irrigated acre receives this amount. From past experience, however, he knows that he is unlikely to actually receive W_1 units of water. If he receives less than W_1, marginal returns still exceed marginal cost. But with more than W_1, profits decrease, and he could easily go past $MP = 0$. Therefore, he will probably plan to apply somewhat less than W_1 units of water, perhaps W_2 units with a corresponding yield Y_2. The yield difference, $Y_1 - Y_2$, represents the yield sacrifice in the risk adjustment to avoid losses. Depending on the accuracy of the farmer's estimate of expected water supply W_1, his ability to absorb temporary financial losses, and his degree of risk aversion, the farmer will consistently underirrigate, relative to the economic optimum. Evidence of this phenomenon has occurred in West Pakistan, which has an irrigation system similar to that of northern India. Pakistani farmers typically respond to increased canal-water supplies by extending their cropped acreage rather than increasing the water-application rate. West Pakistan has a problem of increasing soil salinity due to underirrigation, and increasing the rate of water application would be beneficial (see Garth N. Jones and Raymond L. Anderson, *The Problem of Under-Irrigation in West Pakistan: Research and Study Needs* [Fort Collins: Colorado State University, 1971], p. 3).

[10] *Cicer arietinum* or chick pea, a legume.

[11] Gram is generally considered a dry-land crop, and its continued importance under Bhakra irrigation apparently came as a surprise to some evaluators of the project. They suggested gram's popularity might be due to tradition and the fact that it requires light, sandy soil and little labor and has had fairly good market prices (see Punjab Board of Economic Inquiry, *Report on Cropping Patterns of Hissar District* [Chandigarh: Economic and Statistical Organization, Punjab, 1965], p. 8). This report unfortunately completely neglected the problems of the canal-water supply itself. Tube-well–irrigated farms in the area with a completely controllable and certain water supply grow relatively little gram, as shown by local village record books. Many farms with separate tube-well- and canal-irrigated sections clearly show the contrast.

[12] Richard B. Reidinger (*Canal Irrigation and Institutions in North India: Microstudy and Evaluation* [Ph.D. diss., Duke University, 1971], esp. pp. 235–61) compares crop patterns and economics under canal and tube-well irrigation.

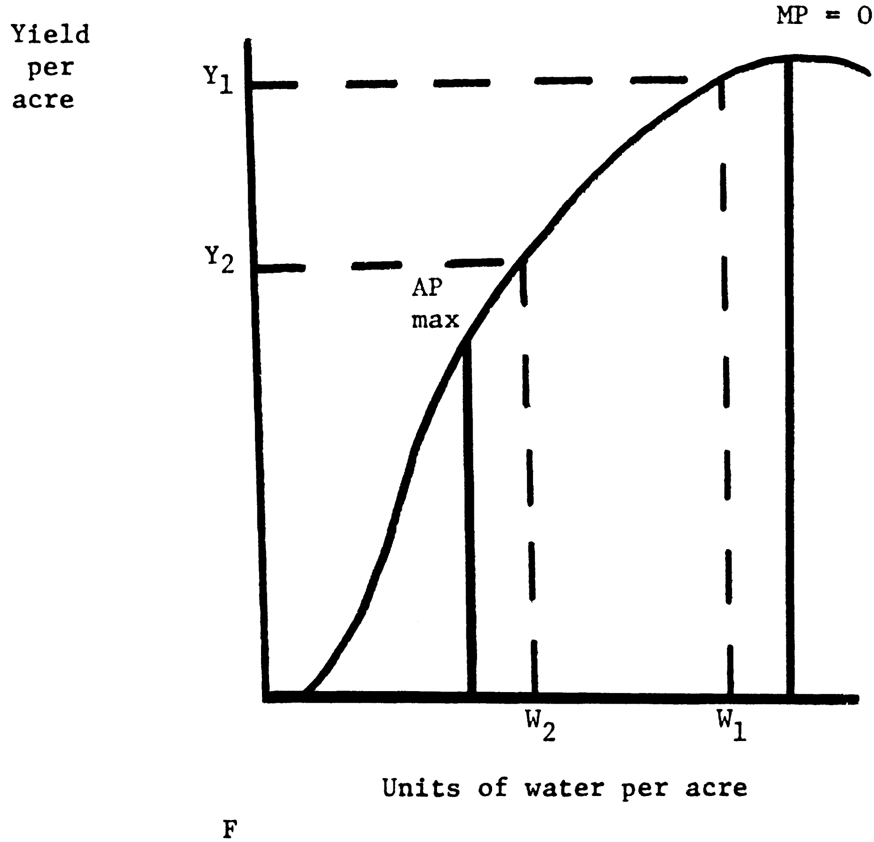

FIG. 1.—Production function for water

General Characteristics of the System of Canal Irrigation

The system of canal irrigation—including operation, design, and administration—developed largely during British times when objectives and conditions differed greatly from those of the present.[13] Both new Bhakra and old Western Jumna canals serve the study area, and the close similarity between the two systems indicates the extent to which the traditional system of canal irrigation has been institutionalized, or carried over into the modern system. The principal difference between them is the water source; Bhakra canals receive water from the 8 million–acre-foot reservoir of the modern, multipurpose Bhakra Dam, whereas Western Jumna canals depend on the unregulated flow of the Jumna River. The same traditional system of irrigation very likely exists in much of northern India (and West

[13] W. Eric Gustafson and Richard B. Reidinger ("Delivery of Canal Water in North India and West Pakistan," *Economic and Political Weekly*, December 25, 1971, pp. A151–62) examine the historical basis of modern irrigation in northern India and West Pakistan.

Pakistan), where modern canal irrigation developed largely under the Northern India Canal and Drainage Act of 1873, where the engineering traditions of the Thomason Civil Engineering College at Roorkee remain strong, and where canal irrigation facilities are generally owned and operated by the government.

A prominent characteristic of both systems is the lack of water-supply flexibility and control by both the farmers and the operating engineers. Engineers operating the system have very little discretionary control over the irrigation-water supply. Physical control facilities, such as gates and checks built into the system, are minimal. The engineers are further bound by the operating rules, and they must generally follow a predetermined schedule approved by their superiors. The system is apparently intended to operate more or less automatically, just as during British times it was to provide "equitable distribution [of water] without any interference by the canal establishment—which is an important advantage to the irrigating community."[14] Each individual farmer receives a share of the available water supply according to the number of acres he owns. But he has no control over the timing and quantity of this water—neither when he will receive his share nor how much of his total share he will receive in any given turn. The system thus provides no formal facility through which farmers can match available water supply to crop water needs, and no way for him to compensate for the largely unpredictable changes in water use by his crop due to climatic variations. Crop damage from soil moisture deficits is generally irreversible and can substantially reduce yields below potential levels.

The rationing system itself is strictly administrative. A fixed water levy is charged per acre irrigated, regardless of the quantity of water applied; the amount paid for water does not reflect its marginal value. A set of institutionalized decision rules governs the sharing of the available water supply at all levels within the canal system, and no farmer can legally obtain more than his share. The quantity of each share varies directly with landholding size. In contrast, electricity generated at the dam is sold on a per unit basis, and more power sold brings in additional revenue for the project. Consideration of the power market will likely affect management decisions to release water according to electricity demand versus irrigation needs.

The total amount of water available to each farmer is severely limited; each season most farmers can irrigate only about one-third of their land

[14] J. Clibborne, *Irrigation Work in India*, rev. G. T. Anthony (Roorkee: Thomason College, 1924), p. 146. This work formed a part of the well-known "Roorkee Treatise on Civil Engineering" of the Thomason College. Lack of discretionary control implied by this quote may have had a benefit, for instance, in reducing corruption, when a major purpose of irrigation was to achieve for a colonial government a maximum amount of famine protection at minimum cost in supervisory manpower and capital. But such a system may not match the needs of modern India and the new agricultural technologies.

included in the canal service area.[15] In fact, the planned irrigation intensity for the Bhakra system is 62 percent total for winter and summer seasons combined.[16] The engineers interviewed indicated that a factor of 2.4 cusecs[17] per thousand acres served or commanded was used in designing the system.[18] This figure is empirical, and is roughly equivalent to 400 acres per cusec. In contrast, a similar factor used in the western United States averaged 75–100 acres per cusec.[19] Augmenting the shortage of available water is the high seepage from the generally unlined canals.[20] One common estimate of seepage losses is that on an average 47 percent of the water entering at the head of the system is lost before reaching the farmers' fields, with losses of 20 percent in main canals and branches, 6 percent in distributaries, and 21 percent in the watercourses leading to the fields.[21]

[15] Reflecting a common justification for the low water availability, John Mellor states that "water will generally produce a higher return if it is spread relatively thinly. As more and more water is given per acre, the yield per acre rises, but returns per acre-inch of water decline. Thus the protective policy of making relatively small quantities of water available per acre ensures the highest returns" (John W. Mellor et al., *Developing Rural India: Plan and Practice* [Ithaca, N.Y.: Cornell University Press, 1968], p. 43). This apparently neglects net returns. And, in any event, if the farmer is a profit maximizer and can choose the amount of land to irrigate with his fixed quantity of water available, he will choose an amount to irrigate such that each acre is at the profit-maximizing level. A smaller quantity of available water simply results in fewer irrigated acres. Furthermore, in any given soil and climatic region, the technical range of water application possible with a particular crop should be relatively limited, if indeed "water requirements for all crops must be about the same, if they are grown on the same soil and for the same growing season" (Colin Clark, *The Economics of Irrigation* [London: Pergamon Press, 1970], p. 4). As indicated above (n. 9), however, lower application rates and thus higher production per unit of water could easily result from water-supply uncertainty, though at a sacrifice of yields and net returns from the irrigation. Similarly, increasing the marginal cost of irrigation by, for instance, volumetric water charges, should also reduce the application rate. Volumetric charges without certainty would not, however, aid the farmer in increasing yields or maximizing net returns from irrigation.

[16] Ansari, p. 135. Intensity is percentage irrigated out of total irrigable service area, combining both winter and summer seasons.

[17] A rate of flow, cubic feet per second. Roughly, 1 cusec flowing for 24 hours provides 2 acre-feet of water; similarly, 1 cusec for 1 hour provides 1 acre-inch.

[18] Oral communication, S. P. Malhatra, superintending engineer, Hissar Bhakra Circle, Hissar.

[19] Duty is the commonly used term for this design factor, though its use is now out of fashion in the United States. In the western United States, with plentiful water, the duty ranged from 60 to 120 acres per cusec; with moderate water scarcity it ranged from 100 to 200 acres per cusec; and with extreme scarcity, such as in southern California, it sometimes reached 300 acres per cusec (see John A. Widtsoe, *The Principles of Irrigation Practice* [London: Macmillan Co., 1914], pp. 337–46).

[20] Unlined canals do not necessarily result in high seepage losses if they are not in porous soil and if they are kept well puddled and wet. The method of operation for the canals under discussion, however, indicates that the canals will be empty repeatedly during the season. The repeated drying and wetting should produce substantial cracking in the soil lining of the channels.

[21] This is the estimate of R. G. Kennedy in the early 1900s, cited in D. V. Jogleker, *Irrigation Research in India* (New Delhi: Central Board of Irrigation and Power, 1965), p. 56. The water lost, and thus production sacrificed, from this seepage is undoubtedly substantial. If, for instance, 50 percent of the water is lost to seepage, then reducing seepage to zero (admittedly impossible) should double the area irrigated

Rationing at Higher Administrative Levels within the System

At the level of releases into the canal system, the principal elements of the rationing system are the reservoir factor, the capacity factors, and the competition between electricity and irrigation for use of water stored in the reservoir.[22] The reservoir factor governs the general magnitude of releases from the reservoir during a given season. It remains constant for the season and represents an estimate of how much water will be available for irrigation in a given season relative to the maximum possible amount available. If, for example, the water available for a given season is 6.1 million acre-feet in a reservoir with a maximum irrigation storage capacity of 6.8, the reservoir factor is about 0.9. For the cultivator, the reservoir factor can roughly indicate the amount of land to sow in irrigated crops in any given season.

In contrast, the capacity factor changes several times during the season. It indicates how near to full the canal system will operate at any given time relative to designed capacity. It thus determines the general time distribution of the available water during the year. Capacity factors generally follow the same pattern every year and are shown in table 1 for the Bhakra and Western Jumna canal systems.

Especially in the winter, changes in the capacity factor do not match the water need of the crops. The highest winter capacity factors occur in the early part of the season, when crops in seedling stages need relatively less water than later, when they are approaching maturity. In contrast to the capacity factor, water requirements of wheat, for example, increase substantially as the season progresses, as shown in figure 2.

The results for the individual cultivator will likely be a substantial waste of water during the early part of the season, and possibly a shortage later in the season during the grand growth period, when water stress can be most damaging to yields. On the basis of his past experience, the cultivator knows he will receive relatively too much water when he needs it least, and too little when he needs it most. The extent of the resulting waste and damage depends largely on how conservative he is in his farm planning at the beginning of the season; or specifically, the number of irrigated acres he sows with his fixed and small (relative to his landholding size) irrigation supply.

The reservoir and capacity factors are forms of interseasonal and

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from the canal. But perhaps the largest long-run cost results from damage to the land due to salt accumulation from rising groundwater levels. Each year seepage and the resulting high water table renders about 2 percent of land in northern India unfit for cultivation. Damage often appears first as strips of salt-affected land alongside the canals. Width of the damaged strips varies from a few hundred yards to a mile or so (see J. F. Mistry, "Water Conveyance Efficiency, with Particular Reference to Lining Channels" [paper presented at Water Management Symposium, Punjab Agricultural University, Hissar, March 11–13, 1969], p. 2; and Evans, p. 39).

[22] The reservoir factor and electricity generation apply only to the Bhakra system, since the Western Jumna system has no storage reservoir or hydroelectric facilities.

TABLE 1

CAPACITY FACTORS FOR BHAKRA AND WESTERN JUMNA CANAL SYSTEMS

Month	Bhakra Canals	Western Jumna Canals
Summer:		
April	.50	.28
May	.90	.51
June	.90	.51
July	.80	.52
August	.80	.52
September	.90	.57
Mean summer	.80	.51
Winter:		
October	.90	.45
November	.90	.45
December:		
1–15	.90	.45
15–31	.50	.29
January:		
1–15	.50	.25
15–31	.50	.29
February:		
1–10	.50	.29
11–28	.75	.39
March	.75	.39
Mean winter	.72	.38
Yearly average	.76	.45

SOURCE.—Office of the Chief Engineer, Irrigation Department, Government of Haryana, Chandigarh.

intraseasonal rationing which are scheduled beforehand, and are reasonably consistent during the season and from year to year. In contrast, water releases for generating electricity are determined on a day-to-day basis. The irrigation system can absorb some limited fluctuation in releases due to changes in demand for electricity. But if the magnitude of the fluctuations is greater than the system can absorb, unscheduled releases must either be made into the irrigation system or passed on downstream. In the latter case the water is lost for this irrigation system, although it may be used further down the river. In the former, the water is unexpected and thus has a low value to cultivators. Similarly, engineers should find it difficult to distribute equitably such unscheduled releases.[23]

The extent to which irrigation is treated as a by-product of reservoir storage cannot be quantitatively estimated due to lack of data, but it should be substantial for several reasons. Demand for electricity by industrialists for their factories, and by wealthier farmers for their tube wells and machinery, is strong and growing. These groups have much influence and political power. In addition, a fertilizer factory established in the area when the Bhakra Dam electricity was surplus uses much power in elec-

[23] Achieving an equitable distribution (supplying each acre with its proportionate share of the available water) was the criterion consistently mentioned by the engineers interviewed and in the quote from Clibborne (see n. 14).

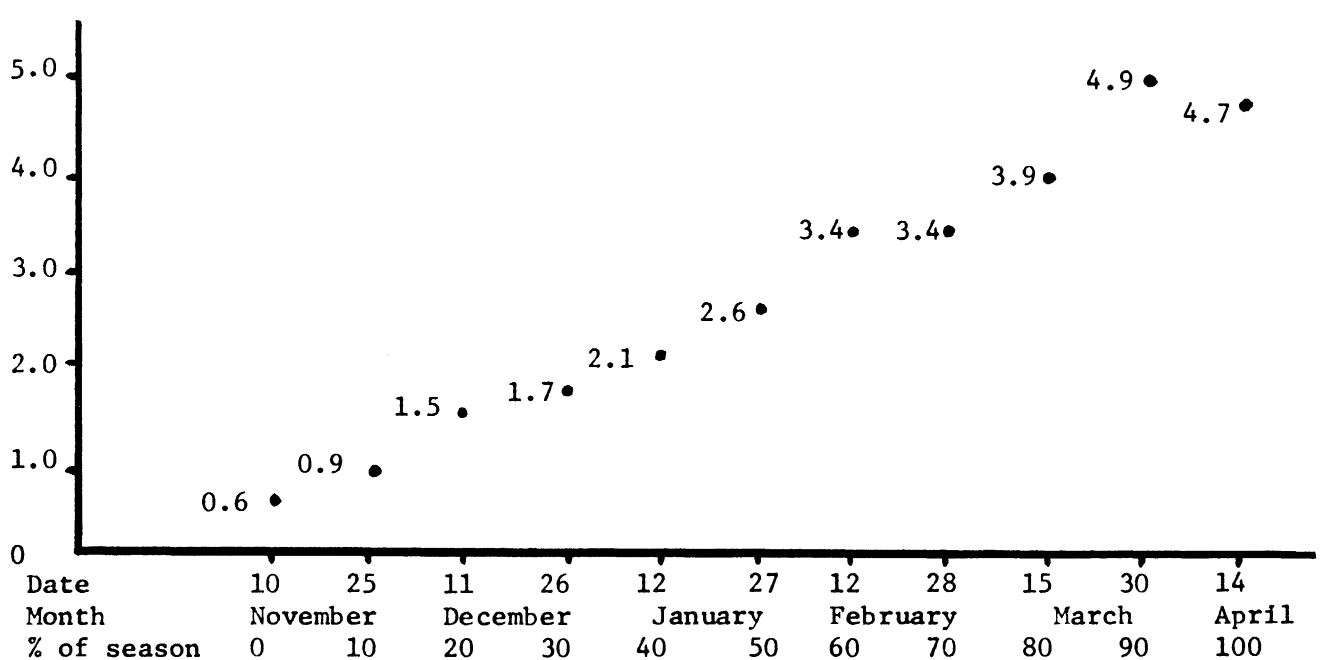

FIG. 2.—Estimated daily water requirements for wheat at various stages of growth in Hissar District, Estimates based on weekly pan evaporation, averaged for 1968–69 and 1969–70; data for previous years on a monthly basis. Period 1968–69 was roughly normal, while 1969–70 had substantial precipitation in late Februrary and March; this accounts for the relatively low water use then. Data from Richard B. Reidinger, "Canal Irrigation and Institutions in North India: Microstudy and

trolysis, although the opportunity cost of that power has increased substantially.[24]

Perhaps most important in deciding the scheduling of releases are the financial returns from power relative to those from irrigation. Every unit of power sold brings in additional revenues for the system. In contrast, additional water supplied for irrigation brings in no additional revenue. Whether the irrigation supply matches the needs of agriculture makes little or no difference in revenues. Revenue from irrigation would be maximized by encouraging farmers to plant as many irrigated acres as possible (through a high initial-capacity factor, for instance) and avoiding crop failure from lack of irrigation.[25] The engineers operating the system are under great pressure to make the system appear as financially successful as possible. In this situation, irrigation understandably may often receive secondary consideration.

The water available for irrigation is divided among the user states on a day-to-day basis according to a politically fixed ratio. Within each state, the water is shared among irrigation circles[26] according to acreage served or commanded. Every circle includes several divisions, each of which receives a share of the available water according to the size of its command area. Fatehabad Division, which includes the case-study area, is the largest of four divisions in the Hissar Bhakra Circle, one of two Bhakra circles which serve Haryana state. Below the division level, water is no longer divided according to area served. Rather, the water rationing results from the interaction of two separate but simultaneous rotations which most directly determine the patterns of each farmer's water supply. It is this interaction which virtually guarantees a highly unpredictable water supply from the individual cultivator's viewpoint.

The Rotation among Channels

Within Fatehabad Division, the channels are divided into three groups. During the season these groups change in preference status (rotate) to receive the available water, generally after every 8 days. Each group down to the smallest distributaries and minors[27] must therefore be operable independently of the other two. Table 2 shows the rotation schedule designating the changing preference status for the 1969–70 *rabi* season. Groups A, B,

[24] When operating at capacity, the fertilizer plant at Nangal utilizes about one-third of the firm generating capacity of Bhakra Dam, which is a major source of power for North India.

[25] The Revenue Department remits the irrigation levy for farmers whose crops fail.

[26] The circles are the highest administrative units below the office of the chief engineer, irrigation, for the state. They may include service areas of, for instance, 2 million acres.

[27] The minors are the smallest controllable channels of the system. A single minor may serve a single village, though not all irrigated villages are served by a single minor. A minor may serve an area of several thousand acres.

and C have capacities of 596, 582, and 539 cusecs, respectively.[28] Each season the schedule and channel groupings are revised by the operating engineers and approved by the chief engineer.

Starting at the beginning of the schedule in table 2, group B had first, group A second, and group C third preference for receiving the available water from October 14, 1969 to October 21, 1969. During that period, if

TABLE 2

HISSAR BHAKRA CANAL CIRCLE, HISSAR—FATEHABAD DIVISION (SIRSA BRANCH SYSTEM): GROUPING OF CHANNELS UNDER ROTATION PROGRAM FROM 14.10.1969 TO 8.4.1970

	Preference Turns		
Dates	I	II	III
Rabi Sowing			
14.10.69–21.10.69	B	A	C
22.10.69–29.10.69	C	B	A
30.10.69–6.11.69	A	C	B
7.11.69–14.11.69	B	A	C
15.11.69–22.11.69	C	B	A
23.11.69–30.11.69	A	C	B
1.12.69–3.12.69		Balancing period	
Rabi Growing			
4.12.69–11.12.69	B	A	C
12.12.69–19.12.69	C	B	A
20.12.69–27.12.69	A	C	B
28.12.69–4.1.70	B	A	C
5.1.70–12.1.70	C	B	A
13.1.70–20.1.70	A	C	B
21.1.70–28.1.70	B	A	C
29.1.70–5.2.70	C	B	A
6.2.70–13.2.70	A	C	B
14.2.70–16.2.70		Balancing period	
Rabi Maturing			
17.2.70–24.2.70	B	A	C
25.2.70–4.3.70	C	B	A
5.3.70–12.3.70	A	C	B
13.3.70–20.3.70	B	A	C
21.3.70–28.3.70	C	B	A
29.3.70–5.4.70	A	C	B
6.4.70–8.4.70		Balancing period	

SOURCE.—Canal Headquarters, Hissar Bhakra Circle, Hissar.

NOTE.—During balancing period channels will run at the discretion of the regulation in charge according to demand and share. Annual closure will be held in January or April 1970 if considered necessary for emergent repairs, and other closure works and the duration of the closure period will depend upon the extent of the nature of repairs considered necessary. Approval dates shown on this schedule were October 10 and November 11, 1969.

[28] An equitable distribution of water requires the capacities to be as equal as possible.

the available supply were 900 cusecs, for example, B would be full, A with second preference would receive the remaining 318 cusecs, and C would receive nothing. The channels to be opened (completely) in group A are chosen such that available capacity in A equals the 318-cusec flow available to it, and thus the open channels tend to operate at capacity. Only with the available flows at capacity levels (1,717 cusecs) would all three groups operate at capacity. On October 22 the channels rotate in priority, with C having first, B second, and A third preference, and so on through the season.

The schedule also divides the winter season (*rabi*) into three stages: *rabi* sowing, *rabi* growing, and *rabi* maturing. Each stage is several weeks long and is followed by a short balancing period. The operating engineers maintain complete water accounts for all channels. Channels receiving relatively less water during a stage have first preference for water available in the balancing period that follows.

The large designed capacity of the canal system relative to the flows normally available during the year necessitates the rotation. The large capacity is needed to transport the large quantities of water available in the monsoon season.[29] The rotation enables the canal system to provide each farmer with a flow of useful size at intervals during the season, even with the severely limited supplies available at the head during the winter dry season. At the same time, the rotation lets a large-capacity canal system operate at much less than optimal state, namely, full capacity, with minimum seepage losses in the largely unlined channels. The policy of adjusting capacity to match flows available should minimize the wetted perimeter per unit of discharge, and thus seepage for all channels in total.[30] Obviously, matching capacity and flows becomes more difficult with increasing variability and unpredictability of releases into the system.

The actual effect of the rotation on the cultivator's water supply depends on the level of releases into the system; as the level of releases relative to capacity decreases, the irrigation interval and timing unpredictability increase. For each farmer, the preference status of the group containing the channel that serves his watercourse provides a rough indication of his water supply at any date during the season. When that preference status is first, he is virtually certain of receiving a full supply; with

[29] Most of the large-scale canal-irrigation projects built during British times depended on river flows which varied greatly between wet and dry seasons. The canal system in its operation had to transport to relatively dry areas large amounts of water available during the monsoon season, and at the same time provide flows of useful size during the dry season. Whether this same type of system makes most effective use of a modern dam with 8.0 million acre-feet of storage capacity is questionable. But its continued use probably indicates a high variability in releases from the dam.

[30] A large channel running partially empty wets a larger surface relative to its rate of flow than when it is running full. Seepage losses are generally proportional to wetted surface area. Similarly, a partially full canal exposes more water surface for evaporation, relative to the rate of flow. Seepage and evaporation losses per unit of flow therefore increase as flow relative to capacity decreases.

second preference, he may receive a supply ranging from nothing to full; and with third preference, he will likely receive no water.[31] The preference status changes every 8 days. Each group should therefore receive a full supply at least once every 24 days, and possibly some supply after 16 days, were it not for the *warabandi* rotation.

The Warabandi Rotation among Farmers

Occurring simultaneously with the 8-day channel rotation is the 7-day *warabandi* rotation among farms on the same water course. The *warabandi* rations the water among farms served by a particular watercourse through a roster of fixed turns to receive water. A watercourse may extend 1 or 2 miles in length, and may serve an area of over 1,000 acres containing 100 or more separate farms.[32] Each farm has a turn for receiving water once a week, and the length of that turn is directly proportional to the farm size. The day of the week on which the turn occurs depends primarily on the location of the farm on the watercourse. The quantity of water received by a farmer during his turn depends on the level of supply in the main channel serving his watercourse.[33]

Suppose a farmer owns 10 acres in a 1,000-acre watercourse command or service area. Every week has 168 hours during which each acre in the command area from the watercourse head to its tail must receive its allotment of time. Each acre therefore has a time allotment of 0.168 hours, and the 10-acre farm thus has a turn 1.68 hours long.[34] With the command area of 1,000 acres and the design factor of 2.4 cusecs per 1,000 acres, a correctly designed outlet for this watercourse will provide a flow of 2.4 cusecs when the main channel runs at full supply. During a time allotment of 0.168 hours, a 2.4-cusec flow would provide approximately 0.4 acre-inches for each acre. The farmer with 10 acres would thus receive a total of about 4 acre-inches of water each week if the main canal is at full supply during his turn.[35] He can apply the water anywhere on his farm; he might concentrate it on a couple of acres or spread it thinly over several acres.

[31] For this situation to hold, releases into the system need only vary between about 30 percent and 70 percent of capacity because each group includes roughly one-third of the total capacity.

[32] Fragmented holdings for separate plots belonging to the same farmer are treated as separate farms in the *warabandi.*

[33] This obviously neglects seepage from the watercourse, condition and slope of the watercourse, height of the farmer's land, distance of the land from the watercourse head, and distance from the watercourse itself, all of which greatly affect the quantity of water received by the farmer.

[34] These calculations neglect the adjustment made for filling the watercourse, which reduces the total week's time by 1 minute per acre of watercourse length (203 feet). Since watercourse length is generally limited to about 2 miles, the total adjustment would rarely exceed 1 hour for the whole week.

[35] For any particular cultivator, the supply he actually receives during his turn depends primarily on his farm's location in the watercourse command area, his distance from the watercourse head, its condition between his land and the outlet, the height of his land relative to the outlet and the watercourse, and the cooperation of those farmers ahead of him on the watercourse.

The permanent order of turns in the *warabandi* rotation depends somewhat on agreement and consultation among the cultivators. But the primary responsibility for determining a just and equitable rotation lies with the local canal officers. Once fixed, it remains relatively immutable. A farmer can have his turn changed only if he can prove to the relevant canal officer that the *warabandi* is unjust, inequitable, or improper, or that it caused legal injury. The canal official may alter it if a change is necessitated by engineering changes in the watercourse or its alignment.[36]

The *warabandi* rotation of turns among farmers rations time, or the opportunity to receive water, rather than water itself. It is essentially permanent and continues automatically regardless of the water flow in the channel. If the channel and thus the watercourse were constantly full, the farmer during his weekly turn would receive 0.4 acre-inch of water per acre owned, neglecting seepage from the unlined watercourse. The preceding discussion, however, clearly indicates a highly variable flow in the channels. In fact, the rotation among channels guarantees that flows will range from full to empty repeatedly during the season. The rotation periods for the *warabandi* and the channel rotations differ, and the interaction due to this difference in periods causes a major element of uncertainty in the farmer's water supply.

Interaction of Canal and *Warabandi* Rotations

The canals when empty require some time to fill. During that time only a partial and uncertain water supply is available to the farmers. The channel-rotation schedule therefore allows 1 extra day for filling, in addition to the 7-day *warabandi* rotation. This results in a total of 8 days for each channel rotation. This 8-day period, however, causes an overlap of the two rotations during each following period. Tables 3 and 4 show the effect of this overlap or interaction. To indicate the effect of the channel rotation on the farmer's water supply, the patterns previously mentioned are assumed in the tables. The farmer receives a full supply when his group has first preference, an unpredictable supply during second preference, and no supply during third preference. The 8-day canal rotation and the 7-day *warabandi* rotation are compared in table 3. Each farmer's turn always occurs on the same day of the week. To indicate the intraseasonal pattern of water supply for individual farmers as a result of the interaction of the two rotations, the data in table 3 are transposed to a day-of-the-week basis in table 4.

Table 4 indicates a common, though not dependable, pattern: a turn of full supply followed by turns of unpredictable supply and no supply. The pattern of water supply for a particular day of the week, however, may violate this pattern several times during the season. Because of the interaction of the two rotations, two consecutive turns of the same preference

[36] J. L. Jain, *Northern India Canal and Drainage Act, Act No. VIII of 1873, Punjab State Wells Act, 1954; with Rules, Notifications, and Latest Case Laws*, 2d ed. (Chandigarh: Jain's Law Agency, 1968), sec. 68, pp. 45–48.

TABLE 3

INTERACTION OF *Warabandi* AND CHANNEL ROTATION IN GROUP B: HYPOTHETICAL WATER SUPPLIES UNDER CHANNEL ROTATION ACCORDING TO DAY OF MONTH AND DAY OF WEEK, *Rabi* 1969

	OCTOBER		NOVEMBER		DECEMBER		JANUARY		FEBRUARY		MARCH		APRIL	
DAY OF MONTH	Channel Flow Level	Day of Week	Channel Flow Level	Day of Week	Channel Flow Level	Day of Week	Channel Flow Level	Day of Week	Channel Flow Level	Day of Week	Channel Flow Level	Day of Week	Channel Flow Level	Day of Week
1	...	...	0	Sa	B	M	+	Th	?	Su	?	Su	0	W
2	...	...	0	Su	B	Tu	+	Fr	?	M	?	M	0	Th
3	...	...	0	M	B	W	+	Sa	?	Tu	?	Tu	0	Fr
4	...	...	0	Tu	±	Th	+	Su	?	W	?	W	0	Sa
5	...	...	0	W	+	Fr	?	M	?	Th	0	Th	0	Su
6	...	...	0	Th	+	Sa	?	Tu	0	Fr	0	Fr	B	M
7	...	...	±	Fr	+	Su	?	W	0	Sa	0	Sa	B	Tu
8	...	...	+	Sa	+	M	?	Th	0	Su	0	Su	B	W
9	...	...	+	Su	+	Tu	?	Fr	0	M	0	M	...	...
10	...	...	+	M	+	W	?	Sa	0	Tu	0	Tu	...	...
11	...	...	+	Tu	+	Th	?	Su	0	W	0	W	...	...
12	...	...	+	W	?	Fr	?	M	0	Th	0	Th	...	...
13	...	...	+	Th	?	Sa	0	Tu	0	Fr	±	Fr	...	...
14	±	Tu	+	Fr	?	Su	0	W	B	Sa	+	Sa	...	...
15	+	W	?	Sa	?	M	0	Th	B	Su	+	Su	...	...
16	+	Th	?	Su	?	Tu	0	Fr	B	M	+	M	...	...
17	+	Fr	?	M	?	W	0	Sa	±	Tu	+	Tu	...	...
18	+	Sa	?	Tu	?	Th	0	Su	+	W	+	W	...	...
19	+	Su	?	W	?	Fr	0	M	+	Th	+	Th	...	...
20	+	M	?	Th	0	Sa	0	Tu	+	Fr	+	Fr	...	...
21	+	Tu	?	Fr	0	Su	±	W	+	Sa	?	Sa	...	...
22	?	W	?	Sa	0	M	+	Th	+	Su	?	Su	...	...
23	?	Th	0	Su	0	Tu	+	Fr	+	M	?	M	...	...
24	?	Fr	0	M	0	W	+	Sa	+	Tu	?	Tu	...	...
25	?	Sa	0	Tu	0	Th	+	Su	?	W	?	W	...	...
26	?	Su	0	W	0	Fr	+	M	?	Th	?	Th	...	...
27	?	M	0	Th	0	Sa	+	Tu	?	Fr	?	Fr	...	...
28	?	Tu	0	Fr	±	Su	+	W	?	Sa	?	Sa	...	...
29	?	W	0	Sa	+	M	?	Th	...	...	0	Su	...	...
30	0	Th	0	Su	+	Tu	?	Fr	...	...	0	M	...	...
31	0	Fr	...	...	+	W	?	Sa	...	...	0	Tu	...	...

NOTE.—Symbols and assumptions: +—first preference for group B, assume full flow; ?—second preference for group B, assume unpredictable flow; 0—third preference for group B, assume no flow; ±—canal filling on first day of first preference, unpredictable flow; and B—balancing period turn, unpredictable flow.

TABLE 4

PATTERN OF WATER SUPPLIED TO FARMERS UNDER GROUP B COMMAND DURING THE SEASON, ACCORDING TO INTERACTION OF *Warabandi* AND CHANNEL ROTATION

WEEK OF THE SEASON	DAY OF THE WEEK ON WHICH FARMER'S TURN OCCURS						
	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
1	...	...	±	+	+	+	+
2	+	+	+	?	?	?	?
3	?	?	?	?	0	0	0
4	0	0	0	0	0	±	+
5	+	+	+	+	+	+	?
6	?	?	?	?	?	?	?
7	0	0	0	0	0	0	0
8	0	B	B	B	±	+	+
9	+	+	+	+	+	?	?
10	?	?	?	?	?	?	0
11	0	0	0	0	0	0	0
12	±	+	+	+	+	+	+
13	+	?	?	?	?	?	?
14	?	?	0	0	0	0	0
15	0	0	0	±	+	+	+
16	+	+	+	+	?	?	?
17	?	?	?	?	?	0	0
18	0	0	0	0	0	0	B
19	B	B	±	+	+	+	+
20	+	+	+	?	?	?	?
21	?	?	?	?	0	0	0
22	0	0	0	0	0	±	+
23	+	+	+	+	+	+	?
24	?	?	?	?	?	?	?
25	0	0	0	0	0	0	0
26	0	B	B	B	...	...	...

NOTE.—Symbols and assumptions same as in table 3.

status commonly occur. For example, Sunday, Tuesday, Thursday, Friday, and Saturday all have two consecutive empty turns; for Sunday and Thursday this occurs twice in the season. Two such turns guarantee the farmer an interval of at least 3 weeks without water, even if by chance he gets a full supply when his group has second preference. If he receives no effective supply during that second preference turn, the interval will extend to 4 weeks. Further, if the farmer's turn occurs on the first day of first-preference status for his group, his supply is unpredictable because the canals are filling. Such a turn occurs at least once in the season for all farmers except those on Monday and Saturday. Similarly, the occurrence of any balancing-period turns introduces additional uncertainty in future water supplies for all except Thursday and Friday. Even the engineers cannot know the allocation of water in those turns until very late in the particular stage of the season. Finally, the closure of the canals for annual repairs provides another element of uncertainty. As indicated in table 2, the closure dates are only generally specified.

Thus, although the farmer's water supply often repeats the pattern of full followed by unpredictable and no supply, he cannot depend on this pattern. The interaction of the two rotation systems, along with turns when the canals are filling and when balancing periods occur, constantly alters this pattern. The farmer can, however, be fairly certain of receiving his water at least after 4 weeks. Most farmers interviewed verified this. They felt reasonably certain of receiving water twice a month, but they never knew when during the month they would receive it. While permitting the survival of irrigated agriculture in an arid region, such a water supply makes precise crop and water management difficult, if not impossible.

Resultant Canal Flows under the Institutional Rationing System

Flows in the canals serving the farmer's watercourses integrate all the aspects of canal-water rationing discussed above. Table 5 shows flow levels in three primary canals serving the case-study area. Canal flows as shown are based on canal record books, but modified to reflect the farmers' viewpoint. Whereas canal records show flows in cusecs for every day of the month, the table shows flows relative to capacity arranged by day of the week, with flows less than 80 percent in brackets.[37]

Balsamand Sub Branch (BSB) includes all of group B. Of the three channel groups (A, B, and C), only group B has a single contact point

[37] When canal flows are less than 80 percent, farmers cannot effectively use their water supply (oral communication, B. S. Bansal, deputy commissioner for the Indus Water Treaty, Ministry of Irrigation and Power, Government of India; formerly superintending engineer, Hissar Bhakra Circle and later chief engineer for Haryana on the Bhakra Management Board). Flows of less than 80 percent are largely ineffectual for irrigation use by the farmers because of the watercourse outlet design. As mentioned previously, the watercourse outlets magnify the effect of canal-level fluctuations on the water supply received by the farmer. The magnification becomes especially severe below an 80 percent level of canal supply. In balancing the water supplied to their various canals, engineers do not count flows below 80 percent.

TABLE 5

DISCHARGE AS PERCENTAGE OF CAPACITY BY DAYS OF THE WEEK, *Rabi* 1969–70

	SUNDAY			MONDAY			TUESDAY			WEDNESDAY			THURSDAY			FRIDAY			SATURDAY		
WEEK OF SEASON	BSB	BD	DD	BSB	BD	DD	BSB	BD	DD	BSB	BD	DD	BSB	BD	DD	BSB	BD	DD	BSB	BD	DD
1. Oct. 12–18	...	...	...	...	...	...	93	100	[43]	91	100	[70]	83	100	[60]	98	100	[74]	100	100	94
2. Oct. 19–25	100	100	94	100	100	94	100	100	89	[72]	103	100	[78]	[49]	100	[79]	[57]	100	[79]	[54]	100
3. Oct. 26–Nov. 1	[77]	[57]	96	[78]	[59]	100	[78]	[59]	100	[72]	[49]	100	[5]	[51]	[0]	[0]	[0]	[0]	[0]	[0]	[0]
4. Nov. 2–8	[0]	[0]	[0]	[0]	[0]	[0]	[14]	[0]	[0]	[12]	[19]	[0]	[14]	[15]	[0]	[78]	[78]	[0]	88	91	94
5. Nov. 9–15	[78]	81	94	100	[74]	98	100	100	100	100	100	100	[39]	[65]	100	[49]	[5]	94	[62]	[24]	100
6. Nov. 16–22	[78]	100	[60]	[76]	100	[60]	[76]	100	[52]	[76]	100	[47]	[76]	100	[47]	[76]	100	[47]	[76]	100	[47]
7. Nov. 23–29	[0]	[29]	[0]	[5]	[0]	[0]	[5]	[0]	[18]	[1]	[1]	[0]	[1]	[0]	[0]	[4]	[0]	[0]	[1]	[0]	[0]
8. Nov. 30–Dec. 6	[4]	[0]	[11]	100	100	84	[54]	[14]	100	[78]	[45]	94	100	94	100	100	103	104	100	94	100
9. Dec. 7–13	100	100	100	100	100	100	100	99	100	100	100	100	100	100	100	[62]	100	[60]	[27]	84	[0]
10. Dec. 14–20	[27]	[44]	[0]	[49]	81	[0]	[53]	[78]	[0]	[59]	84	[10]	[24]	[49]	[0]	[27]	[27]	[0]	[0]	[29]	[0]
11. Dec. 21–27	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]
12. Dec. 28–Jan. 3	100	90	[79]	100	87	97	100	88	92	100	88	92	100	90	89	100	92	85	100	92	87
13. Jan. 4–10	100	88	97	[59]	[33]	100	[34]	[0]	[60]	[37]	[28]	[65]	[40]	[36]	[58]	[40]	[33]	[56]	[37]	[26]	[56]
14. Jan. 11–17	[79]	[75]	[67]	[68]	[66]	[60]	[10]	[29]	[0]	[0]	[0]	[0]	[14]	[29]	[0]	[0]	[0]	[0]	[0]	[0]	[0]
15. Jan. 18–24	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	93	[64]	100	100	85	100	[59]	[36]	100	[39]	[12]	100
16. Jan. 25–31	[39]	[8]	100	[49]	[20]	100	[49]	[20]	100	[69]	[41]	100	[59]	[52]	[74]	[65]	[68]	[60]	[78]	[71]	[74]
17. Feb. 1–7	[79]	[78]	[70]	[79]	84	[65]	[79]	85	[60]	[79]	85	[60]	81	85	[70]	[34]	[49]	[0]	[0]	[0]	[0]
18. Feb. 8–14	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	95	85	89
19. Feb. 15–21	100	88	100	100	90	95	100	88	94	98	89	86	100	89	97	100	89	94	100	88	100
20. Feb. 22–28	100	88	94	100	89	100	100	89	97	83	89	89	91	81	100	87	[74]	100	87	[74]	100
21. March 1–7	83	91	100	87	85	81	87	[71]	95	[74]	[49]	95	[0]	[0]	[60]	[10]	[0]	[49]	[14]	[0]	[21]
22. March 8–14	[12]	[0]	[21]	[9]	[0]	[21]	[34]	[16]	[39]	[27]	[39]	[56]	[19]	[31]	[0]	100	88	[21]	100	88	97
23. March 15–21	85	91	[74]	100	90	[70]	100	90	100	100	90	100	100	92	100	100	92	95	81	81	89
24. March 22–28	[77]	[78]	[74]	[79]	85	[56]	[77]	[78]	[56]	[72]	[71]	[56]	[65]	[71]	[56]	[73]	[78]	[56]	[73]	[69]	[56]
25. March 29–April 4	[0]	[0]	[56]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[0]	[17]	[0]	[0]
26. April 5–11	[0]	[0]	[0]	[46]	[78]	[0]	84	88	[76]	85	81	[72]									

SOURCE.—Original data from Canal Daily Discharge Records, Fatehabad Division, Canal Headquarters, Hissar Bhakra Circle, Hissar.

NOTE.—BSB = Balsamand Sub Branch, capacity 512 cusecs; BD = Balsamand Distributary, capacity 292 cusecs; DD = Dewan Distributary, capacity 168 cusecs. Flow Rates below 80 percent are in brackets.

where it receives all its water. Balsamand Sub Branch later divides into Balsamand Distributary (BD) and Dewan Distributary (DD). All are relatively large in size and serve many watercourses and several minors.

The table clearly indicates a high degree of irregularity and uncertainty for the farmers' water supply during the season with respect to both timing and quantity. Several weeks of no effective supply often follow two consecutive weeks of essentially full supply. Furthermore, water-flow patterns in the three channels have no easily recognizable or consistent relationship, although the channels are physically connected and the two distributaries share all the available water from the subbranch.

Thus, canal-irrigation supplies have at least three types of uncertainty or unreliability with which the farmer must contend: the timing of water supplies during the season, the quantity of water to be received at various times during the season and in total, and the timing and quantity of water received at various locations. This uncertainty is in direct contrast to the farmer's allocated turn to receive water, which occurs weekly for a fixed period of time, and the water needs of crops, which generally increase as the season progresses.

Precise and accurate estimation of the effects of an uncertain water supply on production and yields requires the kind of detailed field and experimental data that are at present largely unavailable.[38] The recent research on critical irrigation periods for dwarf wheat, however, can provide a quantitative indication of the effect from varying timing and quantity (as indicated by the number or frequency of irrigations) of water applied. Such research is now fairly widespread in India, although results are sometimes contradictory. Table 6 shows the results of a recent critical-period experiment. Yields generally increase with increasing amounts (frequency in the table) of irrigation, but substantial yield differences also occur with different timings of the same number of irrigations. Clearly, both timing and quantity of water applied affect yields substantially.

Most farmers interviewed felt severely constrained by their canal-water supply, although they generally seemed anxious to take advantage of new crop varieties and to improve their economic situation when possible. Most wanted to install a tube well to supplement their canal water and improve the timeliness of their irrigations, but few could because of the saline groundwater common in the area. The substantial advantage in per acre profitability of tube-well– over canal-irrigated farms indicates the value of timeliness and precise water management, as well as the opportunity cost of not improving the canal system to provide a more controllable, predictable, and certain water supply.[39]

[38] Available field data, especially for canal irrigation, generally do not include the measured amount of water used or the exact timing of the application. And experimental data unfortunately usually reflect the attempt to maximize yields with optimum conditions, rather than exploring the production surface.

[39] Reidinger (pp. 208–311) provides a detailed comparison and analysis of performance and economics for private tube-well– and canal-irrigated (and dry-land)

TABLE 6

EFFECT OF VARYING SCHEDULE AND FREQUENCY OF IRRIGATIONS ON YIELD OF DWARF WHEAT (SONORA 64)

Treatments	Schedule of Irrigation (Days after Sowing)						Irrigation Frequency	Grain Yield (q/ha)	Relative Yield (%)
	25 (Crown Root)	45 (Tillering)	65 (Jointing)	85 (Flowering)	105 (Milk)	120 (Dough)			
A	−	−	−	−	−	−	0	9.3	100
B	+	−	−	−	−	−	1	30.4	327
C	−	−	+	−	−	−	1	20.6	222
D	−	−	−	−	+	−	1	10.5	113
E	+	−	+	−	−	−	2	34.2	368
F	−	−	+	−	+	−	2	26.1	280
G	+	−	−	−	+	−	2	31.6	340
H	+	−	+	−	+	−	3	35.4	381
I	+	+	+	−	+	−	4	41.8	450
J	+	−	+	+	+	−	4	42.8	460
K	+	−	+	−	+	+	4	37.6	404
L	+	+	+	+	+	−	5	47.8	514
M	+	+	+	−	+	+	5	43.3	466
N	+	−	+	+	+	+	5	43.5	468
P	+	+	+	+	+	+	6	51.1	550
Rainfall (mm)	−	−	−	−	0.8	12.0	...	...	...

SOURCE.—N. G. Dastane et al., *Review of Work Done on Water Requirements of Crops in India* (Poona: Navabharat Prakashan, 1970), p. 43.

NOTE.—(+) and (−) indicate irrigation and no irrigation. C.D. or significant difference in yield at the .05 level is 6.0 quintels per hectare. Many similar experiments have been done, and while their results do not all agree quantitatively, the evidence is strong that the dwarfs respond well to irrigation at particular times, especially at crown-root initiation.

Summary and Recommendations

The rationing system tends to assure a high degree of uncertainty in the timing and quantity of water supply received by farmers. And for the individual farmer it virtually guarantees an interval between irrigations varying unpredictably from 1 to several weeks in length during the season. The competition between electricity and irrigation, the capacity factors, and the interaction between the canal and *warabandi* rotations appear as primary causes of this situation. At the same time, the nonmarket nature of the rationing system and its lack of flexibility and controllability largely preclude adjustments to compensate for the uncertainty and variability. A primary virtue of the rationing system is that all recipients apparently share both water and insecurity equally.

Through the uncertainty it produces, as well as the mismatch of water supply to crop needs, the rationing system can greatly limit the effectiveness of water use by farmers, and thus the overall returns to large-scale canal irrigation. Clearly, the new high-yielding varieties—the basis of the green revolution—cannot approach their potential without precise water management. This requires flexibility and control, or at least predictability of the water supply. The government recognizes the need for improved water management with canal irrigation.[40] As indicated above, however, the major difficulty lies not so much with the operating engineers or with the farmers, but rather with the traditional system of canal irrigation itself.

The canal system as an institution which rations water thus exemplifies the impact of economic or production institutions on agricultural development. Institutional changes to provide greater certainty or control of water supply would allow farmers to reduce risk adjustments, improve water and crop management, and thus increase yields and profits. The preceding analysis of the rationing system suggests several changes which should enable it more closely to meet the needs of modern agriculture and to increase the predictability, certainty, and control of the farmer's canal-water supply.

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farms in the case-study area. The study indicates a substantial yield and profit advantage with controllable tube-well irrigation compared to uncontrollable canal irrigation. Even though the water application (frequency) was higher under tube-well irrigation, the regression coefficient for water application (especially on dwarf wheat) was also larger compared to canal irrigation, indicating a higher marginal product for water use with tube-well irrigation. T. V. Moorti (*A Comparative Study of Well Irrigation in Aligargh Distric, India* [Ithaca, N.Y.: Cornell University, Department of Agricultural Economics, Occasional Paper no. 29, 1970], p. 53) reports similar results in comparing private tube wells and state-owned tube wells which are not controllable by the farmer. He attributed this to a combination of good water timing and control, use of high-yielding varieties, and high use of other inputs under private tube-well irrigation.

[40] For example, at a meeting of the Central Board of Irrigation and Power in December 1969, G. A. Narshimha Rao, then chairman of the Central Water and Power Commission, stated that "I consider it the duty of the Irrigation Engineer to supply the required quantity of water at the right time on the farm."

At the level of releases into the system, matching the capacity factors more closely to crop water needs could improve the farmers' efficiency of water use for both irrigation and stored soil moisture. For example, in October just after the monsoon, the soil-moisture reservoir should be near capacity. Nevertheless, the initial winter-season capacity factors appear relatively high compared to levels later in the season, especially during the grand growth period. To say that "cultivators will have to be taught—if indeed they do not know this already—that lesser quantities of water are needed for plants in seedling stages than when they are growing rapidly toward maturity"[41] neglects the root of the problem. Cultivators cannot change the capacity factors that guarantee that the largest water supplies of the season will occur during the seedling stages when the quantity of water needed is relatively low. Even during the stages of maximum consumptive use of water by the crop, the capacity factor never reaches its early-season level.

The competition between electricity and irrigation introduces a much more complicated problem. To explore this would require a detailed analysis of both private and social returns from improving the supply of water for irrigation, as compared to treating irrigation as a by-product and letting power production take precedence as may be happening at present. Putting the irrigation levy on a volumetric basis would provide decision makers with a rough indication of the marginal value of irrigation water, and with an incentive to give more emphasis to agriculture. A volumetric water levy should also encourage more judicious water use by farmers.[42] It would not, however, help them equate marginal revenues and marginal costs and attain economic efficiency in water use.

At lower levels of the rationing system, the policy of sharing the available water among farmers on the basis of their landholding size certainly violates the spirit and the letter of a major stated national objective: equalization of income distribution.[43] In a country like India, with its

[41] Evans, p. 21.

[42] Much literature on Indian irrigation has emphasized the need for volumetric water charges. The *Report of the Indian Irrigation Commission of 1901–03* provides a cogent statement of the case. The situation with respect to volumetric water levies has changed little since then (see *Report of the Indian Irrigation Commission, 1901–03*, pt. 1. *General* [Calcutta: Superintendent of Government Printing, 1903], pp. 90–98); Ansari (pp. 109–13) presents a brief discussion of the report's conclusions in this regard. Inefficient use of water—overirrigation—is often attributed to the per acre levy as an argument for volumetric water charges. The marginal cost of applying additional water to the same acre is very low, and indeed the farmer who receives much more water than he planned for could easily overirrigate. A volumetric water levy for a highly uncertain water supply may possibly reduce the tendency to irrigate beyond the point of zero marginal product. It would not, however, help the farmer to reach the economic optimum and thus increase net returns per acre from irrigation; that is, while the levy would increase technical water-use efficiency (average product). it would not help in reaching economic efficiency without a more certain or controllable water supply.

[43] "The basic goal is a rapid increase in the standard of living of the people, through measures which also promote equality and justice. . . . planning should result

concentration of landholdings,[44] such a policy favors the relatively few wealthy landlords. And giving more water to the larger farmers should provide little or no economic advantage in terms of production and, in fact, may have a negative effect. Substantial evidence exists indicating that small farms have a per acre productivity at least as high as that of large farms under roughly comparable conditions.[45] Analysis of field data collected in the case study area verifies this. With the present low intensity of irrigation, allocating relatively more water to small farmers should therefore not sacrifice total production, and could result in increases. Finally, a policy that places the small farmers at a competitive disadvantage in resource availability could drive them back toward subsistence agriculture, and ultimately off the farm. In view of the large numbers involved and the limited opportunity in industry in the foreseeable future, a policy retaining labor in agriculture appears worthwhile. It seems much more beneficial to provide a more equal sharing of the scarce water, which provides the basis for raising income in arid agriculture.

Increasing the predictability of water supply would enable more effective water use by the farmer. More knowledge or forewarning of future flows should enable him to plan and manage his farm more precisely. News media, and especially radio broadcasting, could quickly spread news of expected water supplies for the season, for the system as a whole, and for particular times and areas. For example, water released from the Bhakra Dam requires about 3 days to reach Hissar; broadcasting information on releases would give at least a few days forewarning. Broader dissemination of information supposedly already available—such as the

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in greater equality of income and wealth, and there should be progressive reduction of concentration of incomes, wealth, and economic power" (*Fourth Five Year Plan*, p. 4).

[44] Of the agricultural families, 60.8 percent hold less than 2.5 acres and own 6.3 percent of the agricultural land, while 3.4 percent of the families hold more than 25 acres and own 34.5 percent of the land (see *National Sample Survey*, Report no. 10 [Delhi: Government of India, 1958], p. 47, cited in P. V. John, *Some Aspects of the Structure of Indian Agricultural Economy, 1947–48 to 1961–62* [Bombay: Asia Publishing House, 1968], p. 91). Indeed, allocation of canal water in direct proportion to the number of acres owned should encourage concentration of holdings, contrary to national policy. By retaining their land, the large landowners receive a larger share of the available water. Canal irrigation may also affect the other major land-tenure policy —consolidation of fragmented holdings—which is necessary for efficient agricultural management. As indicated in the analysis, the canal-water rationing system can result in a water supply that is good at one location and bad at another nearby. A farmer's fragmented holdings can thus reduce the risk that all his crops will receive a poor canal-water supply.

[45] A. M. Khusro ("Returns to Scale in Indian Agriculture," reprinted in A. M. Khusro, *Readings in Agricultural Development* [New Delhi: Allied Publishers Private, 1968], pp. 123–59) presents results indicating that, in fact, output per acre decreases as farm size increases, as well as references to research showing similar results. This also occurs in the Intensive Agricultural Development Districts (see Expert Committee on Assessment and Evaluation, Ministry of Food, Agriculture, Community Development and Cooperation, *Modernizing Indian Agriculture: Report on the Intensive Agricultural District Programme (1960–68)* (New Delhi: Government of India, 1969), 1:30, commonly known as the *Sen Report*.

channel-rotation schedule—should also receive more emphasis. No farmers questioned about it had seen a channel-rotation schedule in several years. Knowledge of the rotation schedule well before the season begins would also benefit the farmers; for the 1969 *rabi* schedule, the approval dates, October 10 and November 11, are too late to enable effective diffusion for the *rabi* sowing period. An irrigation extension agent could also play a vital role in dissemination and interpretation of information such as the rotation schedule and releases into the system.

The interaction of the rotation among channels and the farmers' *warabandi* rotation produces much of the uncertainty. As indicated above, much of the problem results from the unequal periods of the two rotations. Making the two periods equal in length would eliminate the interaction problems. A 7-day canal-rotation period, for instance, would match the 7-day *warabandi* rotation, thus eliminating the overlap.

The problem of the day required for filling, however, would still exist. Farmers with turns on the first day of the week would always face a very uncertain water supply and possibly always receive relatively less water. Compressing the turns of all the farmers on the watercourse into 6 days and allowing the water on the filling day to go to waste[46] (which should not amount to much until the canals reach full supply levels) would reduce each farmer's time allotment by one-seventh but might still result in production gains, depending on the quantity of water actually lost on the filling day and the value of the resulting increased certainty of water supply.

Alternatively, an association of farmers on the same watercourse could oversee the distribution of whatever water comes during the filling day, rather than wasting it. Such a water users' association would absorb the uncertainty of the water supply on the filling day because no farmer would depend on it. At the same time, it could provide more water control for the farmers and additional water to those for whom the water was most valuable, perhaps by auctioning the water available on the filling day to the highest bidders. A mutual company–type organization could provide for a just sharing or rebating of net income from water sales according to some specified formula.[47]

In the long run, devising an organization to replace entirely the *warabandi* system appears highly beneficial. Designing a workable system for Indian conditions presents many problems, but the likely returns from greater flexibility and control by the farmers certainly justifies further research and investigation. Field interviews indicated that some informal water trading—both interseasonal and intraseasonal—among neighboring

[46] The law does not actually require use of the water (see N. D. Gulhati, *Administration and Financing of Irrigation Works in India*, Publication no. 77 [New Delhi: Central Board of Irrigation and Power, 1965], p. 79).

[47] Various types of effective local water users' associations operate, for example, in Japan, Taiwan, and Indonesia, especially Bali.

farmers already occurs, even though the canal authorities apparently consider it illegal. Such trading exists in highly diverse situations in the world,[48] and has much to recommend it as an approach to economic efficiency. A water users' association could provide the institutional framework to encourage and expedite the transfer of water to those farmers for whom it has the highest marginal value, while protecting the rights of the economically and politically weak.

Certainly the development of some type of water users' association among the farmers represents only one of many possible alternatives. The method of providing more flexibility and control in farm-water supply remains an open question, but an undeniable need for both does exist. With further advancement of agricultural technology, the need for more precise management of water, and the requisite flexibility and controllability of its supply, will increase. Lack of these characteristics in the canal system could greatly impede future agricultural development and leave untapped much of the potential of the new agricultural technologies.

[48] Substantial water trading apparently occurs in the western United States, though it has rarely received much emphasis. Wells A. Hutchins (*Mutual Irrigation Companies in California and Utah*, Bulletin no. 8 [Washington, D.C.: Farm Credit Administration, Cooperative Division, 1936], pp. 123–24) briefly discusses it. For more recent analysis of such transfers, see Raymond L. Anderson, "The Irrigation Water Rental Market: A Case Study," *Agricultural Economics Research* 12, no. 2 (April 1961): 54–58; and B. Delworth Gardner and Herbert H. Fullerton, "Transfer Restrictions and Misallocations of Irrigation Water," *American Journal of Agricultural Economics* 50, no. 3 (August 1968): 55–71. Similarly, organized water trading as an integral part of a distribution system occurs in the traditional *huerta* (irrigation association among farmers) of Alicante, Spain, and dates back several hundred years; see the section on Alicante in the forthcoming book by Arthur Maass and Raymond Anderson dealing with irrigation water distribution in three areas of the western United States and three in Spain. Raymond L. Anderson and Arthur Maass (*A Simulation of Irrigation Systems: The Effect of Water Supply and Operating Rules on Production and Income on Irrigated Farms*, Technical Bulletin no. 1431 [Washington, D.C.: Department of Agriculture, Economic Research Service, 1971], p. 6) briefly mention the study.