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Sustainable Development of Irrigation water in Chinese Taipei

Yi-Fong Ho

Associate Specialist, Irrigation and Engineering Division, Forestry Department, Council of Agriculture, *Chinese Taipei*

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Abstract

Taiwan is an island with total area of 36,000 km^2; 70% of the island is approximately covered by mountains and 30% the plains below the elevation of 100 m. Because two-thirds of the island are steep and mountainous lands with relative short courses, 73% of rainfall flows directly into the sea and only less than 30% of water is preserved. Although the average annual rainfall is approximately 2,500 mm, about 2.6 times that of the world, 80% of the rain falls in the wet season, from May to October, which makes it difficult to allocate and utilize the water resources. Owing to the uneven rainfall, irrigation is necessary for crop production, depending on the availability of facilities and the practices of management. In 2001, the total water used in Taiwan amounted to 18.5 billion m^3, of which about 11.5 billion m^3 or 62% of the total was used for irrigation. Since the Tropic of Cancer passes through its middle, the island is characterized by subtropical oceanic zones which allow two or more crops to be grown yearly, wherever water is available. This paper mainly focuses on introducing the aspects dealing with irrigation performance and management prevailed in Taiwan, and some improvements due to the recent environmental and socio-economic changes, for the purpose of sustaining use of irrigation water in Taiwan. Irrigation development is no longer merely a problem of irrigation engineering. The functions and beneficial results of paddy fields and irrigation systems on production, ecology, and livelihood should all be further investigated and evaluated. In order to incorporate with Taiwan's future long-term agricultural policy, some innovative measures for sustainable development of irrigation water in Taiwan should be implemented.

Key Words

Irrigation Association, Irrigation Water, Irrigation

Introduction

Taiwan, an island facing the People's Republic of China across the Taiwan Strait, locates on the west rim of Pacific Ocean. With total area of 36,000 km^2, 70% of the island is approximately covered by mountains and 30% the plains below the elevation of 100 m. The Central Mountain almost extends through the entire length of the island and divides it into two unequal parts of the East and the West coasts.

There are 151 rivers distributing island-wide and only nine of them each possess a basin area exceeding 1,000 km^2. Because two-thirds of the island are steep and mountainous lands with relative short courses, only five rivers possess slopes below 1/1,000 such that 73% of rainfall flows directly into the sea and only less than 30% of water is preserved. Rainfall in Taiwan, situated in the Asian monsoon region, is abundant, but distributing unevenly both in time and space, which is not quite consistent with the growing seasons of crops. The average annual rainfall is approximately 2,500 mm, which is about 2.6 times that of the world, resulting in a total volume of 90.4 billion m^3 of water over the island. However, 80% of the rain falls in the wet season, from May to October, which makes it difficult to allocate and utilize the water resources.

According to statistics of total water use in 2001, total water use in Taiwan is about 18.476 billion m^3, in which 13.012 billion m^3 or 70% is used for agricultural water, comprising irrigation water in the amount of 11.479 billion m^3 (paddy rice irrigation of 8.037 billion m^3, upland irrigation of 3.442 billion m^3), fish-culture water of 1.419 billion m^3, and livestock water of 0.114 billion m^3 as shown in Table 1.

Table 1. Water used in Taiwan, 2001

Unit: $10^6 m^3$

Category\Area	North	Central	South	East	Total	(%)
Agricultural water use	2,284	5,724	2,571	2,434	13,012	(70.42)
(1)Irrigation	2,187	5,122	1,767	2,403	11,479	(62.13)
(2)Fish-culture use	88	557	747	28	1,419	(7.68)
(3)Livestock use	9	45	57	3	114	(0.62)
Domestic water supply	1,973	809	847	95	3,725	(20.16)
Industrial water use	630	503	549	59	1,740	(9.42)
Total water use	4,886	7,036	3,967	2,588	18,476	(100)

Source: Water Resources Bureau, Ministry of Economic Affairs, 2003.

In comparison with the historic statistics, the use amount of agricultural water is cut down year by year, from 16.35 billion m^3 in 1982 to 13.012 billion m^3 in 2001, 21% decrease of range that is 3.34 billion m^3 as shown in Table 2. 88% of agricultural water is used for irrigation, therefore, this paper mainly focuses on introducing the aspects dealing with irrigation performance and management prevailed in Taiwan, and some improvements due to the recent environmental and socio-economic changes, for the purpose of sustaining use of irrigation water in Taiwan.

Table 2. Water used in Taiwan, from 1982 to 2001

Unit: $10^6 m^3$

Year\ Category	Irrigation			Fish-culture use	Livestock use	Agricultural water use
	Paddy rice	Upland	Subtotal			
1982	13,184	864	14,048	2,225	78	16,351
1983	12,649	812	13,461	2,383	88	15,932
1984	11,822	795	12,617	2,380	93	15,090
1985	11,779	780	12,559	2,361	93	15,013
1986	11,402	969	12,371	2,431	100	14,902
1987	11,149	1,006	12,155	2,566	105	14,826
1988	10,677	1,099	11,776	2,793	108	14,677
1989	10,893	1,048	11,941	2,916	117	14,974
1990	11,096	1,032	12,128	3,149	116	15,393
1991	9,379	953	10,332	3,093	129	13,554
1992	9,413	890	10,303	3,064	134	13,501
1993	8,767	946	9,713	2,801	136	12,650

Year\ Category	Irrigation			Fish-culture use	Livestock use	Agricultural water use
	Paddy rice	Upland	Subtotal			
1994	6,888	3,050	9,938	3,097	140	13,175
1995	10,161	1,019	11,180	3,138	146	14,464
1996	7,746	2,453	10,199	3,146	151	13,496
1997	8,398	2,391	10,789	2,583	197	13,569
1998	8,334	2,348	10,682	1,463	109	12,254
1999	7,869	2,554	10,423	1,512	117	12,052
2000	8,165	2,442	10,607	1,584	118	12,309
2001	8,037	3,442	11,479	1,419	114	13,012

Source: Water Resources Bureau, Ministry of Economic Affairs, 2003.

Evolution of Irrigation Development in Taiwan

First Stage (before 1895)

It began about 300 years ago, around China's Yuan Dynasty, when immigrants came from mainland China. Taiwan was still a barren island at that time. As rice is the principal crop for the residents in Taiwan, the irrigation facilities on the island had been developed mainly for rice production in the form of small scale and primitive construction mostly privately owned. Most of the irrigation systems were built and managed by the farmers themselves without any coordination among the water users and supervision by the government at all. Because of the sparse population and the plentiful water, about 200,000 hectares of farmlands had been under irrigation by 1895 without any further management and, therefore, no need to restrict water use.

Second Stage (from 1896 to 1945)

During the period of Japanese occupation of the island, a set of rules and regulations calling for the registration of those private irrigation systems were promulgated by the Japanese government in order to put them under government supervision for well management and maintenance, and 181 public canal cooperatives were founded to take in charge for irrigation operation and management. In the meantime, the government canal cooperatives were also established for operation and management of those canals, which were constructed by government. Later on, the Japanese government further reorganized the public canal cooperatives and government canal cooperatives

into irrigation cooperatives. In this period, the existing systems were remodeled, consolidated, and enlarged, as well as plenty of new systems such as Tao-yuan Canal, Chia-nan Canal, etc. were constructed. The irrigation area was increased to about 560,000 hectares

Third Stage (after 1945)

Due to the devastation in the period of World War II, the irrigation area in Taiwan was reduced sharp to 260,000 hectares. After the Taiwan's recovery from Japanese occupation, the main irrigation works were concentrated on rehabilitation of existing facilities and followed by resumption of all unfinished pre-war projects with the government's subsidies. First of all, rehabilitation of the damaged irrigation systems were the important works to be done, and about 260,000 hectares of irrigation area were rehabilitated. Since 1956, some new development for economical utilization of water resources projects related to irrigation for agricultural production were conducted. The new development projects covered: (1) large-scale irrigation, such as Shih-men Canal irrigation system, Kuan-shan Canal irrigation system, Lu-yeh Canal irrigation system etc., (2) multi-purpose reservoirs, such as Shih-man Dam, Tseng-wen Dam, Min-teh Dam, Pai-ho Dam, etc., (3) groundwater development, mainly developed in Yun-lin and Ping-tung area, and (4) tidal land and river-bed land reclamation. By 1962, the irrigation area was increased to 676,384 hectares, which was the highest record in Taiwan then. For the efficient utilization of the existing water resources, rotational irrigation practice, canal lining project, land consolidation projects were implemented.

Irrigation Organizations and Operation

In the early stages of irrigation development in Taiwan, relevant facilities were constructed by the private sectors. However, due to the lack of effective management, disputes over water use were not unusual and water resources were used rather ineffectively. Consequently, irrigation organizations were formed and established to resolve such conflicts and to improve the water management efficiency, for the purpose of effective utilization of the potential water resources. The government later on intervened and granted these irrigation organizations the status of public juridical person to advance their operation and management capabilities.

Features of Irrigation Associations

According to the General Rules Governing in Organization of Irrigation Associations, the 17 irrigation associations, under the supervision of the Council of Agriculture, are legal and organized by farmers and take the following six

major responsibilities:

A.Construction, improvement, maintenance, and management of irrigation and drainage facilities;

B.Prevention and rescue of disasters/damages to the irrigation and drainage facilities;

C.Fund raising and foundation establishment for the needs of irrigation undertakings;

D.Research and development of irrigation and drainage benefits;

E.Support to relevant government policies in connection with the land, agriculture, industrial policies and rural reconstruction; and

F.Other activities as legally designated by the competent authority.

The 17 Irrigation Associations have been generally established in accordance with local geographical conditions and economic benefits. And their official titles were given according to the major regions that they are servicing, or the river/canal systems. Currently, the 17 Irrigation Associations, with their respective locations shown in Fig. 1, have been entitled the public juridical persons as already mentioned previously. In order to perform the legally prescribed duties, the organizational setup of a typical irrigation association may include: Chairman, the highest official in the organization; the General Manager who is next in command and responsible to the Chairman; the Chief Engineer, along with the level of the General Manager; and eight divisions, running the business right under the supervision of the General Manager. The eight divisions and offices as well as respective sections thereof may be described as follows:

1.Engineering Division: Design section; Construction Section and Evaluation Section;

2.Management Division: Mechanic and Electricity Section; Irrigation Section; and Supervision Section;

3.Finance Division: Revenue Section; Property Section; and Adjustment Section;

4.Administrative Division: Document Section; General Affairs Section; and Cashier Section;

5.Audit Office: Budget Section; Accounting Section; and Statistics Section;

6.Personnel Office: Assignment Section and Rating Section;

7.Security Office: First Section and Second Section; and

8.Computer Office.

Another three offices out of the headquarter, also under the General Manager, are the Management office, Working Station and Irrigation Group. All the field activities, including operation and maintenance (O&M) in the fields of the service areas and association-owned facilities, are carried out by the local

regional management offices, the so-called "working stations", assisted by irrigation groups in their service areas respectively. Besides, some Irrigation Associations have water source and canal working stations which are in charge of controlling and supplying the water. A typical organizational structure of irrigation association is schematically shown in Fig. 2.

Irrigation Operation

Prior to the irrigation season, a preliminary water distribution plan is to be worked out by the management division at the head office according to the government policy, production goals, the existing reservoir/ponds storage and water release, water flows at diversion weirs, other available water sources, past records of irrigation requirements, canal conveyance losses, rotational irrigation intervals, and time of irrigation etc. The prepared plan is handed through regional management offices or directly to the working stations for further study and discussions with irrigation groups, and finalization.

The finalized water distribution plan is to be strictly carried out by the working stations. The canal operators of stations are in charge of regulation and controlling water flows along main canal, laterals, and sub-laterals. The irrigation supervision are in charge of water control and measurement at turnout gates on laterals or sub-laterals, and of inspection on farm-level water distribution which are undertaken by irrigation groups in their individual irrigation areas. Till the year of 2001, the total irrigation area managed by the Irrigation Associations is 374,451 hectares, and the total length of the leading, main, lateral, and sub-lateral canals, and farm supplying ditches is 44,399 km. Especially, the length of farm supplying ditches is 30,870 km., around 70% of the total. The average length of supplying ditches per hectares is 82 meters.

Presently, 81.14% of irrigation water in Taiwan was diverted from rivers, 10.89% from reservoirs and various ponds, 5.42% pumped from groundwater, and 2.55% from other sources.

Irrigation Situation Nowaday

Since the Tropic of Cancer passes through its middle, the island is characterized by subtropical oceanic zones which allowing two or more crops being grown yearly, wherever water is available. Since rice is the staple food in Taiwan, irrigation has been essentially developed for rice cultivation.

Cropping Patterns

Since rice is the predominant crop in Taiwan, it is usually used for the determination of the most common cropping patterns according to the availability of irrigation water. The cropping patterns commonly adopted in Taiwan may be classified into seven groups including: (1) double rice cropping system, (2) single rice cropping system, (3) one rice crop in two year cropping rotation, (4) one rice crop in three year cropping rotation, (5) two rice crop in three year cropping rotation, (6) the year-round growing system for perennial crops, and (7) upland crop rotation system, as illustratively shown in Fig. 3. Of the total area of 374,451 hectares served by the 17 Irrigation Associations in 2001, the double rice-crop area was 185,567 hectares, the single rice-crop area, 22,340 hectares, the rotation cropping area (including two and three year rotation), 81,987 hectares, and the upland crop area, 10,631 hectares

Continuous Irrigation

Taiwan was a barren island in the old day. When immigrants came from mainland China and settled, agricultural activities started and canals were built to convey water from streams for irrigation. During this period, the population was spare and the water was plentiful, there was no need to restrict water use. The irrigation practice in those days was of the continuous method. Starting with the transplanting of rice, the paddy field is continuously supplied with water of 50 mm to 60 mm in depth through the period of rice plants except weeding, fertilizer application and harvesting. Water is applied day and night flowing into the paddy field at one end and out at the other end without any control. Such practice results in high consumption of water. In general, the irrigation rate was as low as 330 hectares/cms in most area.

Rotational Irrigation

Due to the rapid growth of population, development of industry, and the expansion of irrigated areas in 1950, the water use of cultivable lands and existing water resources for irrigation and other objects was approaching to a limit. To develop new water resources is not only costly but also time consuming. In order to reduce the unnecessary waste of continuous irrigation, the government actively initiated the promotion of "Rotational Irrigation Practice" and thus directed the irrigation management into a scientific level in 1956. Three main types of rotational irrigation popularly prevailed in Taiwan are described as follow cases:

Case A: Rotation by sections in the main canal, the water is conveyed in turn to different sections of the main canal.

Case B: Rotation by sections in the laterals or sub-laterals, the main canal keeps continuous flow while water is conveyed to the various sections of laterals or sub-laterals successively.

Case C: Rotation by farm ditches, the water flowing in the farm ditches are intermittent while the flow in the main, laterals and sub-laterals are kept continuous.

In order to facilitate this method of irrigation, the irrigation system is designed to simultaneously deliver irrigation water into each individual "rotation area" of about 50 hectares. Each rotation area is subdivided into five or six rotation units of about 10 hectares each in size. Every rotation area is provided with one turnout gate, one measuring device, and several division boxes as shown in Fig. 4. Water flowing through the turnout is measured and rotated among the rotation units within the rotation area with the amount of water and interval of irrigation adjusted according to the actual rotation unit size, soil, effective rainfall and conveyance losses.

In the aforementioned three types of rotational irrigation, the water is allocated appropriately to farmers in order and time lapse such that various crop fields may get the necessary amount of water respectively, in which case A or B is mostly suitable for drought period, while case C is usually applied in practical irrigation. According to the experiment and practice, rotational irrigation could save about 20-30% in water without producing any bad effect on rice growth and harvest such that the irrigation rate could be increased up to 800 hectares in a cubic meter per second; furthermore, plant growth, fertilizer saving, and elimination of water dispute could be achieved.

Land Consolidation

Since land holdings in Taiwan have been very small and fragmental, the irrigation operation and management is inconvenient due to the inadequate and insufficient irrigation and road systems. A land consolidation program was started in 1958 to amalgamate the small and irregular farm plots and consolidate them by exchange and redistribution of farm roads, and irrigation and drainage systems were made for better transportation, direct irrigation and effective drainage, thereby improving farm level structures. A typical rotational area and water distribution system through land consolidation program is shown in Fig. 5.

As to the water distribution on paddy fields with land consolidation, irrigation water flows continuously through the turnout gate and controlled by

the measuring devices into the rotation area, and irrigation is rotated among rotation units. In the land consolidation area, each block area of about 10-14 hectares is regarded as a rotation unit, and each rotation unit is subdivided in several plots with area of 0.2 hectares –0.4 hectares, about 100-120 m long and 20-40 m wide. Irrigation water is delivered to each plot from the farm supply ditch directly, while in the rotational area without land consolidation, the water is supplied to the plot passing from field to field. Up to 1998, the total completed area is about 380,000 hectares

Problems Encountered

As rice is the predominant crop in Taiwan in the early stage, paddy is grown wherever possible, so, there had been a surplus crop of rice production year after year. For example, the paddy harvested area was 502,018 hectares with an annual brown rice production of 639,000 M.T. in 1945, increased to a high record of 786,343 hectares with a maximum production of 2,712,000 M.T. in 1976.

Moreover, consumption patterns have been changing with increasing wealth, the average year consumption of rice per person has fallen from 134 kg. in 1974 to 59 kg. in 1996. In addition, the international price of rice has been low, and there has never been a fixed export market for Taiwan's rice. In order to balance out production and marketing of rice, a paddy diversion program was initiated in 1984 to divert the use of paddy field from the production of rice to alternative crops. The total diversified paddy field (including set-aside field) was from 43,700 crop-hectares in 1984, increased to 260,000 crop-hectares in 1997. Under this program, theoretically, there should have a large amount of irrigation water to be saved for other use.

Actually, about 76% of the irrigation water is river off-take with local and time difference, and has been seriously polluted, which is very difficult to be used by other users. Besides, the diversified paddy field is not concentrated, and irrigation is still needed for those paddy fields which have not been diversified, and for the upland crops fields, so a certain amount of discharge in canal is necessary for canal conveyance loss. As a result, not only no more water can be saved for other users, but also the irrigation management becomes more complicated. At the present stage of economic growth in Taiwan, water demand has been increasing and the production of additional new water sources has become more costly. No new irrigation projects can be implemented for rice production due to economic feasibility factors. However, in order to maintain paddy field with area of about 350,000 hectares for self-sufficiency in food-crop products so as to ensure the security of food supplies and raise

farmer's income and to narrow the income gap between farmers and non-farm workers, irrigation is still necessary. A certain amount of water is needed to be used for irrigation, but the percentage is decreased year after year. For example, the total amount of irrigation water used in 2001 was about 11.5 billion m^3 or 62% of the total water used in Taiwan, which was much lower than the amount of 13.6 billion m^3 or 81% in 1971.

Prospection

With the increase demand on water for the increasing of population and the expansion of industrialization and urbanization in the last decade, as well as its lower production value per unit use of water, the irrigation water sources in Taiwan is facing the pressure of competition usage from other objects. The acquisition of new water supplies for agricultural irrigation has been become more difficult and costly. However, irrigation water resources are not only essential for agricultural production but also featuring with maintaining the ecological functions. In order to incorporate with Taiwan's future long-term agricultural policy, the main measures for sustainable development of irrigation water in Taiwan are summarized as following:

A. The establishment of a compensation mechanism for transferring of the irrigation water for other purposes should be directed in order to support the water demands of other use objects. The various models on reasonable water use in different areas and different seasons have to be established.

B. In response to raising the use efficiencies and benefits of irrigation water resources, efforts should be made for strengthening improvements in irrigation management and operation techniques, repairing and improving the old existing irrigation system facilities, promoting the pipeline irrigation for upland crops, and providing guidance for the diversification undertakings of the irrigation associations.

C. Accompanying with the development of electronics, the adoption of remote control facilities have to be taken on the irrigation facilities in view of minimizing water loss in canals, monitoring of irrigation water quality in the heavy polluted areas and saving management manpower.

D. Irrigation development is no longer merely a problem of irrigation engineering. The functions and beneficial results of paddy fields and irrigation systems on production, ecology, and livelihood should all be further investigated and evaluated, so as to generally reflect the real value per unit use of irrigation water to the community.

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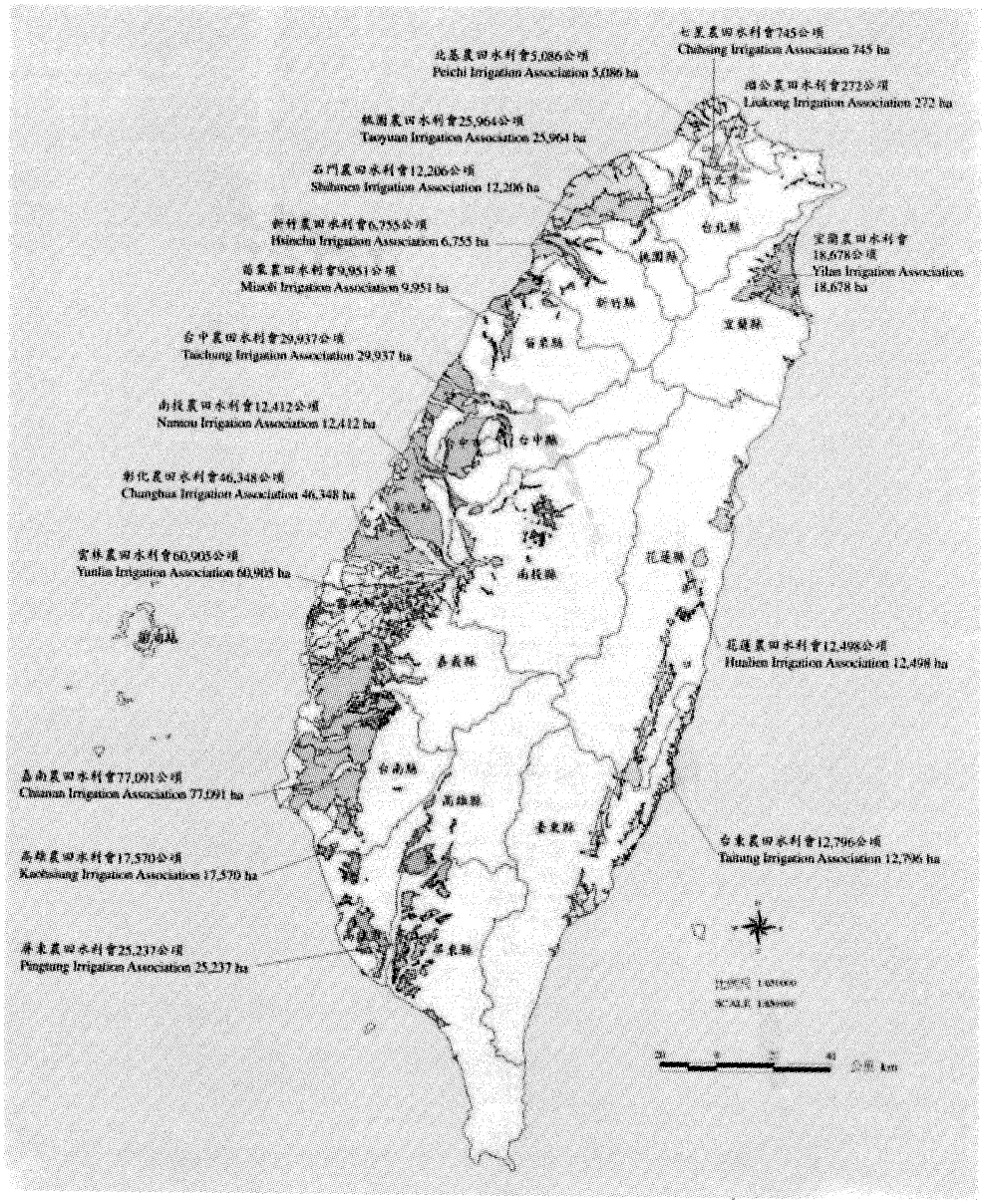


Fig.1. Locations of Present Irrigation Associations and Their Irrigation Area in Taiwan

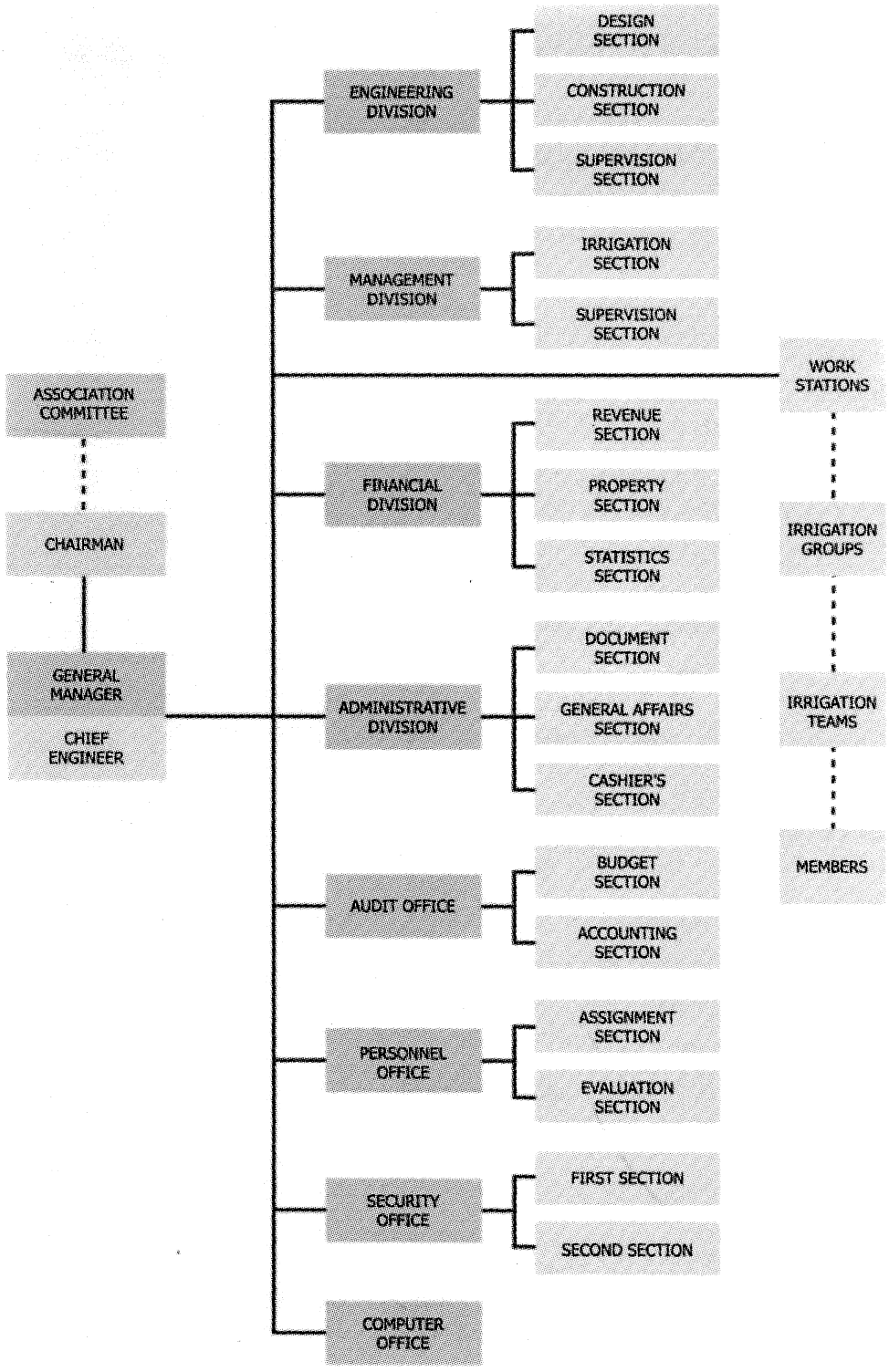
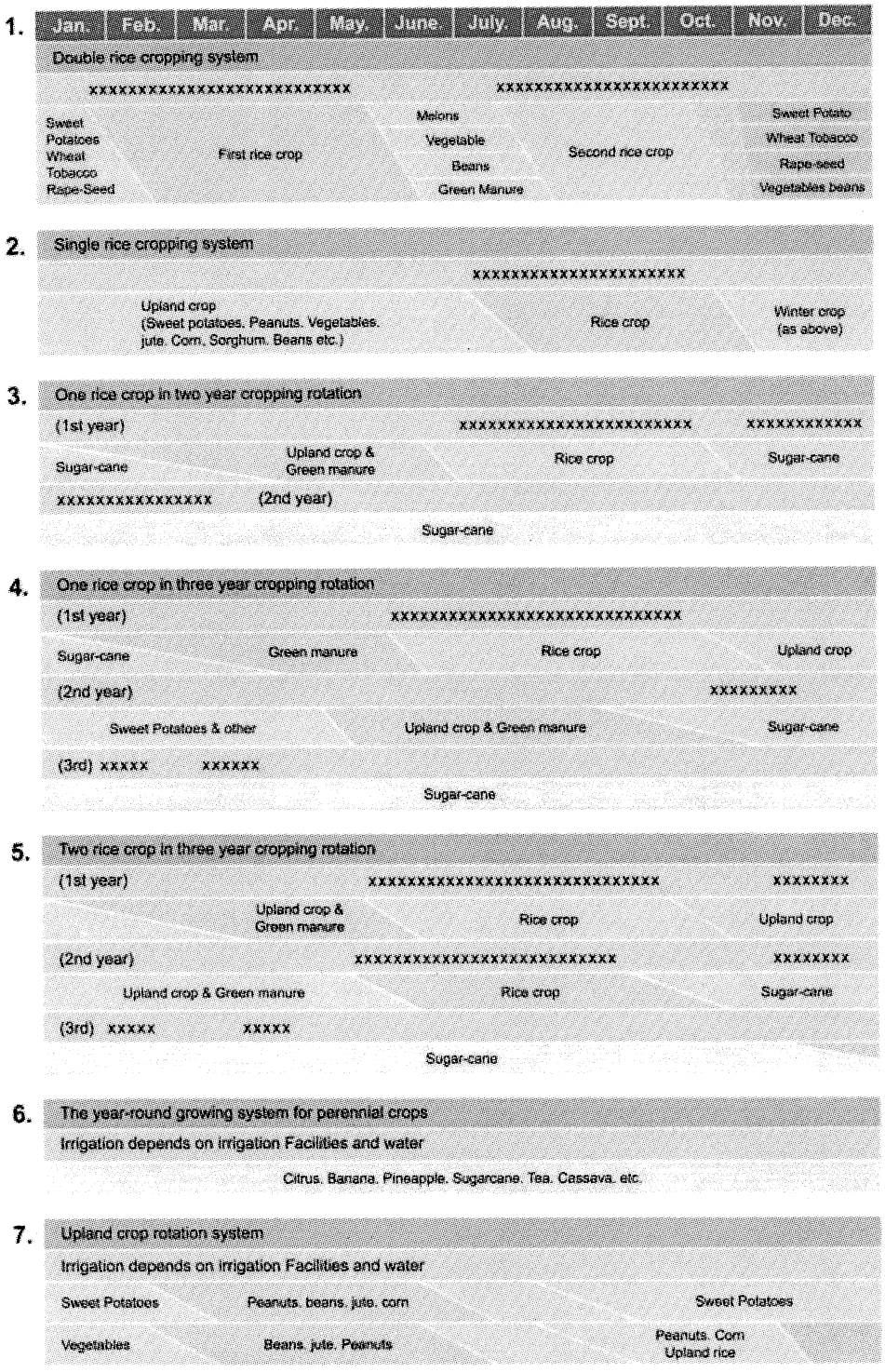


Fig.2. Irrigation Association's Organizational Structural Chart



Legend: "xxx" indicate irrigation period
(Source: L.J. Wen)

Fig.3. Various Cropping Patterns adopted in Taiwan

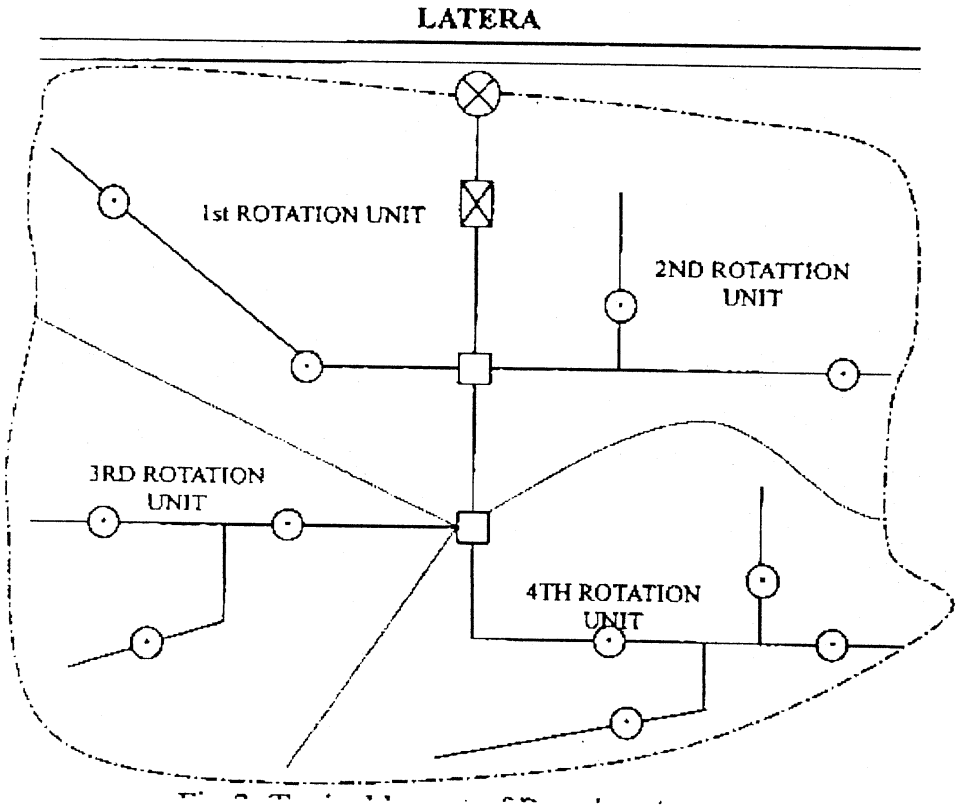


Fig.4. Typical Layout of Rotation Area

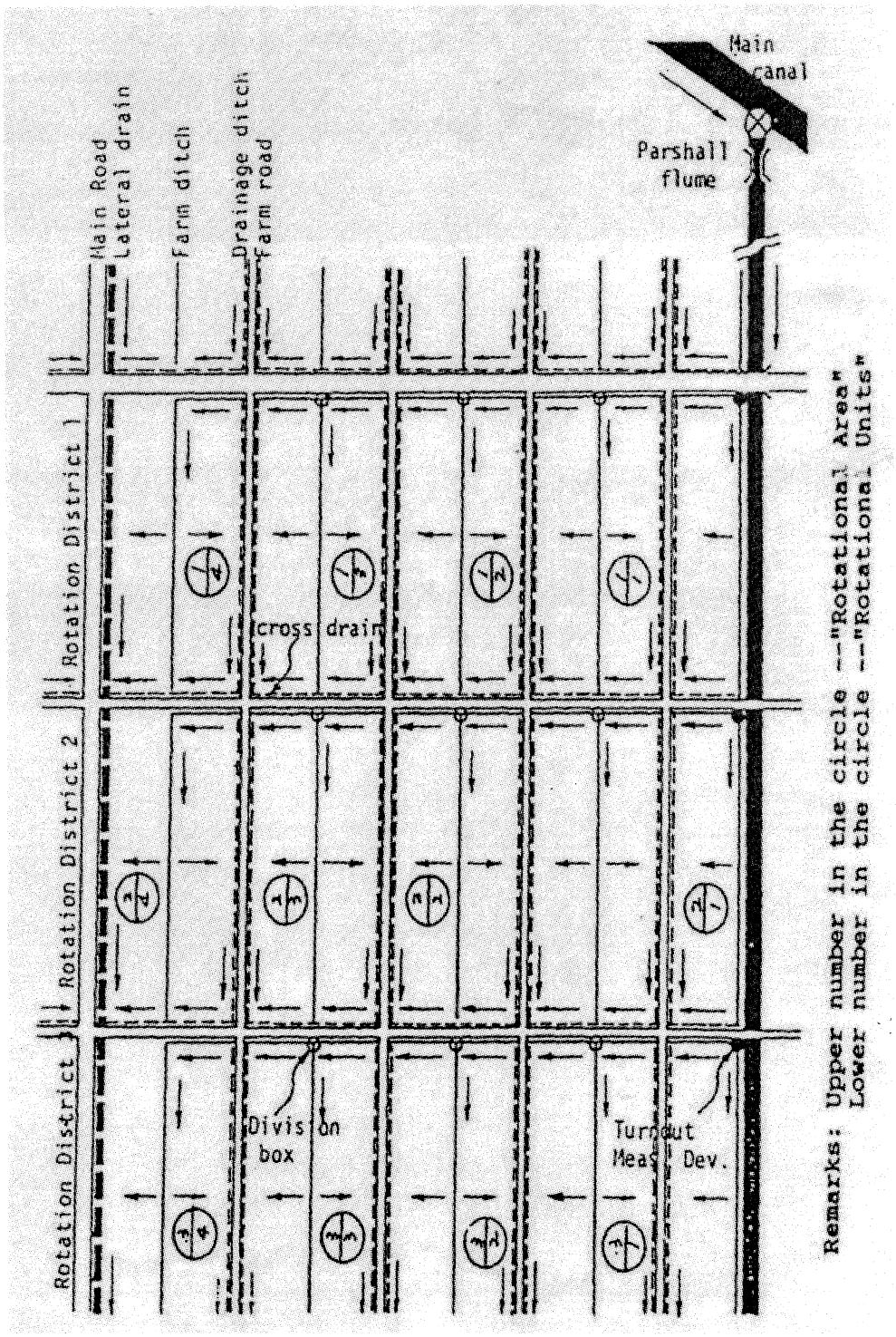


Fig.5. Typical Rotational Area and Water Distribution System through Land Consolidation