Plate 2. Duckbill weir at Tikri distributary

Plate 3. Consultation with farmers at design acceptance meetings

a predetermined discharge and are not too sensitive to upstream water level fluctuations have been considered for minor canal inlets. In sections of the distributary reach where large water level fluctuations are expected, a downstream water level regulator will be installed in front of the module. The flow regulation and measurement system shall consist of different types of orifice modules.

Single orifice module: The Neyrpic orifice module, developed by Neyrpic Laboratories, Grenoble (France), is used as an intake for minor canals. It is a metering device and is suitable when water is supplied on a volumetric basis. For the module to draw the amount of water for which it was designed, water level fluctuations in the parent canal should be small (up to 8 cm). It can be installed directly on the bank of the parent canal.

Double orifice module: In locations with greater variation of discharge in the supply canal, i.e. large variation in water supply level (8 to 15 cm) a double orifice module, an improvement over the single orifice module, will be installed. Its various arrangements with constant upstream and downstream water level gates and regulating check structures are the same as the single orifice module. The double orifice module consists of a thick sill similar to the Neyrpic orifice module and is provided with two vertical metallic covers forming a syphon. The calibrated openings of different width discharge 10 liter/s, 20 liter/s and 30 liter/s or more for a given head.

Automatic gate and orifice combination: If the water level in the parent canal fluctuates beyond tolerable limits for constant flow, a constant downstream water level gate must be installed at the head of the off-taking channel upstream of the Neyrpic single orifice module. Hydraulically automated checks ("Neyrpic automatic gates") have been developed for more accurate water level control than is possible with a conventional hand-operated gate. The operation of these gates relies entirely on the forces in the system itself such as hydrostatic thrust and the weight of the device. These gates provide a constant downstream level for discharge through an orifice. This combination is generally suitable in locations when the discharge of the intake is small compared to the discharge of the parent canal. The intake structure has a protection gate and a constant downstream water level gate before the orifice module. The arrangement for a single orifice module is given in Figure 3.

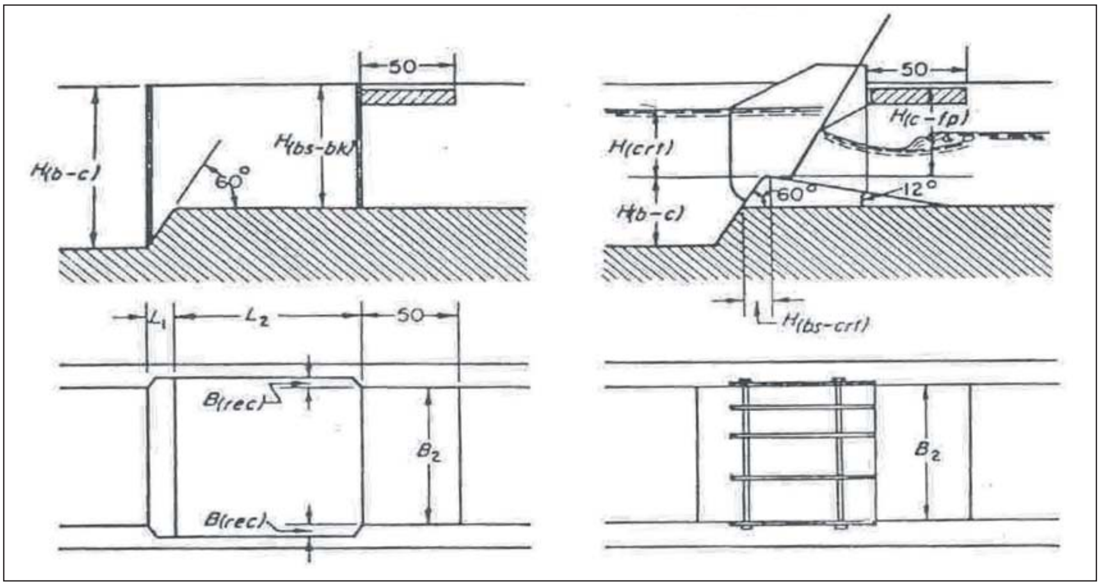

Figure 3. Neyrpic orifice module before and after installation of the fixed plate

Semi-module pipe outlet: A pipe outlet was planned in the command area at the time of initial construction; the discharging capacity is dependent both on upstream as well as downstream water levels. It consists of simple CI pipes of 3″, 4″, 5″ and 6″ diameter or a combination of these depending upon the command area. In the redesign process all outlet discharges are being rationalized up to 1 liter/s capacity according to their actual CCA, calculated using GIS land-use data of the command area.

The semi-module pipe outlet is eminently suitable when the canal has wide banks because an open flume or an orifice semi-module built in such a bank would be much more expensive. These outlets are suitable for drawing the share of silt when it is not possible to achieve a deep setting as required by an open flume or an orifice semi-module. The lead-in pipe is set at or near the bed level and it opens into a tank on the downstream to which an open flume is fitted.

The discharge of a semi-module pipe outlet is independent of the water level in the watercourse or field lateral, but dependent on the water levels in the supply canal, so long as a minimum working head is available for the device. The usual use of semi-modules is to distribute, more or less equitably, upstream variations in the supply canal within their range of operation.

Plate 4. Single orifice module at Majhalgaon Project, India

Modules with moving parts comprise generally complicated mechanisms with the resulting possibility of the moving parts becoming jammed. The use of modules therefore is not being considered in the redesign process.

The outlet consists of a lead-in pipe from the supply canal which discharges into a tank on the outer side of the bank of the supply canal. The upstream end of the lead-in pipe can be placed at any suitable level in the supply canal depending upon the desired silt-draw with the minimum distance between the centre of the lead-in pipe and the canal's FSL of 230 mm. The downstream end of the lead-in pipe may be horizontal or given an upward slope of about 1 to 12 to reduce the depth of the tank. In the downstream wall of the tank a throat is fitted in the form of a precast block and open flume.

The submergence of the throat crest remains less than 50 percent to avoid dependence on water level in the field channel. The throat block is planned to be precast re-inforced concrete according to the required outlet discharge. The top level of the throat block shall be placed equal to the FSL in the supply canal. The main advantages of the precast throat block are: It is robust, it cannot be tampered with easily and if vandalized, it can be replaced without any change to other structure. In the case of re-assessment of outlet commands, throat blocks can be replaced accordingly.

Apart from rehabilitation, many other activities such as diversification and intensification of agriculture, telemetry and SCADA, preparation of an asset inventory, social and environmental guidelines, O&M manuals are part of the consultancy. Rehabilitation is underway and likely to be completed by 2010.

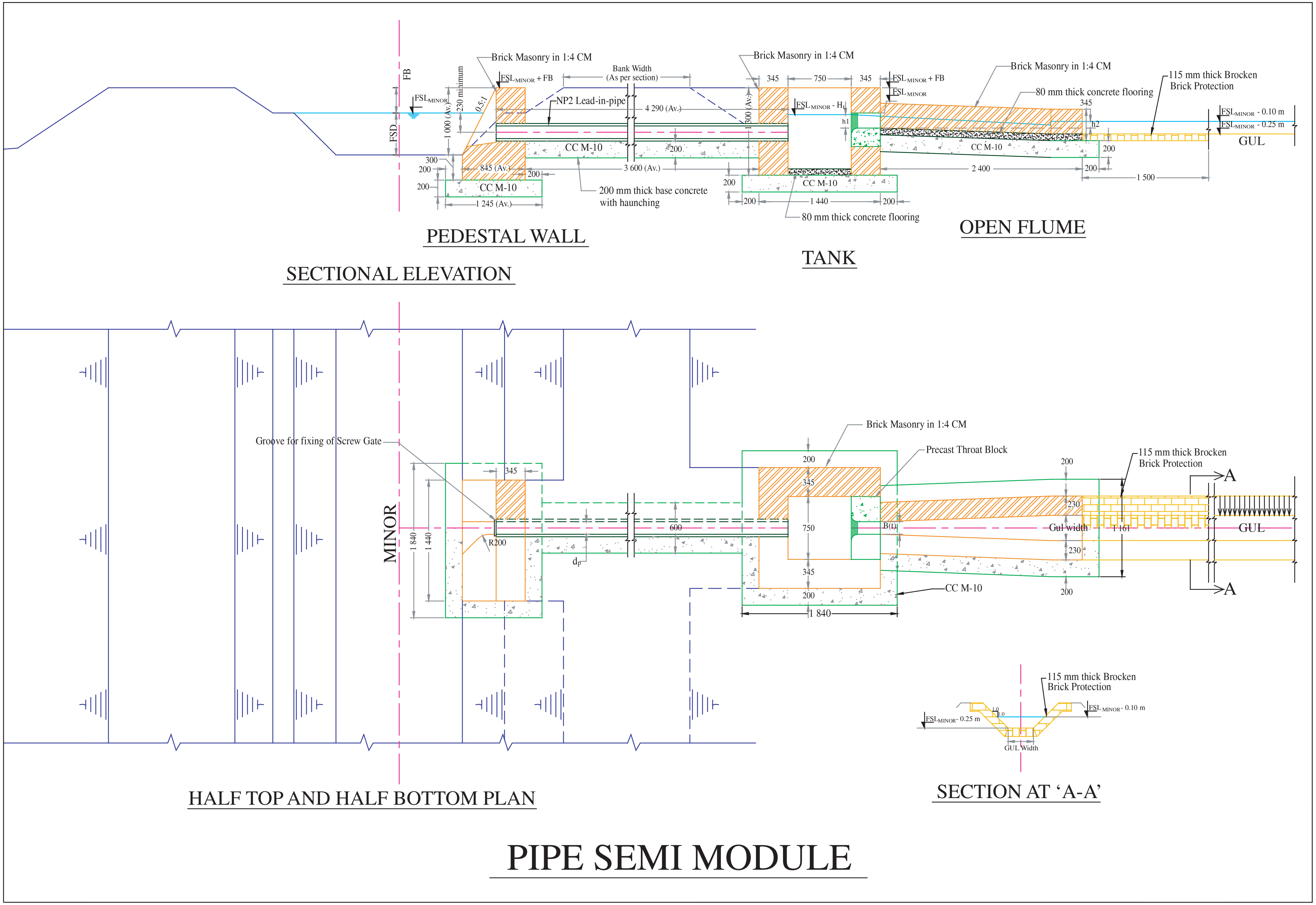

Figure 4. Pipe semi-module

Pumping stations in water resource management and irrigation modernization

Dou Yisong[1]

1. Modern irrigation in China

1.1 Background

Hydroelectric power generation and irrigation in China have undergone significant changes. From 1949 to the end of 2004, hydroelectric power increased from 71 000 kw to 82.159 million kw; during the same period, drainage and irrigation areas have expanded from 250 000 ha (3.78 million *mu*) to 36.91 million ha (553.67 million *mu*) (Table 1).

Table 1. Development of national hydropower, drainage and irrigation

Year	Generated hydroelectric power (million kw)	Drainage and irrigation area (million *mu*)	Fixed station ('000 stations)
1949	0.070	3.78	
1960	3.540	70.00	
1970	13.420	224.88	
1980	53.840	459.00	524.4
1990	68.055	468.38	473.6
2000	77.476	542.68	506.0
2004	82.159	553.67	494.2

2. Pumping stations for water resource management

2.1 Tasks of water resource management

According to Chinese law, water resource management includes water development, utilization, allocation, saving and protection as well as disaster control during floods and drought.

2.2. Functions of pumping stations for water resource management

2.2.1 Irrigation

The benefits of pumping stations are mainly evident in mitigating disasters, such as drought; the most outstanding case is in the arid and semi-arid areas of the northwest region of China. Since the end of the 1950s, many high lift pumping irrigation projects have been constructed in Gansu, Ningxia, Shanxi, Shaanxi and Ningxia Provinces. The development and utilization of water and land resources have enhanced agricultural production in these areas; grain production and farmers' income have increased rapidly. The pumping stations in Jiamakou, Dayudu, Zuncun, Yumankou, Yinhuangrujin selected for field trips for participants at this conference are the five outstanding facilities in Shanxi Province and provide valuable insights into the construction of pumping stations in western regions of China.

2.2.2 Drainage

Besides drought, severe flooding is another disaster for agricultural production. Pumping stations play an important role in drainage. Drainage benefits are most significant in plain–lacustrine areas, such as Jianghan

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Plain in Hubei Province, Sanjiang Plain in Northeast China, Dongting Lake, Boyang Lake, Tai Lake and Chao Lake. Hubei Province's drainage area and power installations are the largest in China. By 2004, Hubei had constructed 4 205 drainage pumping stations with 8 429 installed pumps, powered by up to 1.21 million kw; the water discharge rate had reached 12 946 m^3/s and the drainage area was 1.506 million ha (22.59 million *mu*). The yearly average discharge in this province is 8 billion m^3. Over the past 20 years, pumping stations have addressed catastrophic floods (1980, 1981, 1983, 1991, 1996, 1998 and 1999). In 1991, large and medium pumping stations drained nearly 10 billion m^3, in disaster reduction terms saving 16 billion yuan.

2.2.3 Transbasin water diversion or water diversion within basins

Because the distribution of water, land, solar and geothermal resources is unbalanced, the utilization and development of water resources in various regions are significantly different. The average runoff volume of the Yangtze, Pearl and Songhua Rivers (3R) is 1 388 billion m^3, while that of the Yellow, Haihe, Huaihe and Liaohe Rivers (4R) is 172 billion m^3. The gross value of industrial and agricultural output of 3R is only 1.2 times greater than that of 4R. The runoff volume per capita of 3R is 3 000 m^3, while that of 4R is only 500 m^3. The runoff volume per *mu* of cultivated land of 3R is 2 652 m^3, while that of 4R is only 285 m^3.

Within the river basin, the water resource and productivity equation is also not completely balanced, especially in some large and medium cities, such as Beijing, Tianjin, Datong, Shenzhen and Qingdao. Population and productivity are concentrated, but water shortage is severe. Many cities are forced to overexploit underground water which has generated serious consequences.

Therefore, we need to launch transbasin or inner basin water diversion nationwide and locally. Since the 1960s, a number of water diversion projects has been constructed. The pumping station has been playing a key or supporting role in these projects. Tables 2, 3, 4 and 5 identify pumping stations and their main technical parameters in various water diversion projects.

2.2.4 Saving water

Water shortages in China are very serious. Total water utilization was once 103 billion m^3 but had increased to 554.8 billion m^3 in 2004. The proportion of agricultural water consumption in total water consumption has decreased to 65 percent from 85 percent in 1980 due to water-saving irrigation measures taken during the 9th and 10th Five-year Plans. However the irrigation water utilization coefficient remains around 0.45, which is far behind developed countries (0.7 to 0.8). This indicates that, on the one hand, the effects of water-saving irrigation measures are evident but on the other hand, there is still great potential for further water-saving irrigation. If we want to push ahead with further water conservancy measures, advanced equipment and facilities (pumps and pumping stations) for supplying pressurized water are essential. The demand is large and areas in need are extensive.

2.2.5 Protecting the water environment and wastewater treatment

With the rapid development of the national economy, the acceleration of urbanization and enhanced standard of living, declining water resources and pollution of the water environment are becoming increasingly serious. According to the Chinese Academy of Engineering research report on the sustainable development of water resources in China, the total volume of polluted water emissions in 1997 was 58.4 billion tonnes; the total volume of polluted water emissions in urban areas will increase to 85–106 billion tonnes in 2030. At present, wastewater treatment cannot match the speed of environmental deterioration, which cannot be effectively controlled. According to incomplete statistics, there were still 297 cities with no wastewater treatment plants by the end of June 2005. By 2010, the government aims to improve wastewater treatment facilities in 50 percent of large cities nationwide and to increase the wastewater treatment capacity of medium cities (county-level cities) and provincial cities to at least 60 percent and over 70 percent, respectively. To realize the aforesaid goals, sewage pumping stations should be constructed. In this context, pumping stations also play a role in environmental protection and wastewater treatment.

Table 2. Main technical parameters of the water diversion project from Luanhe River to Tianjin

Name		Function	Design flow of pumping station (m^3/s)	Pump		Design flow of pump (m^3/s)	Design delivery lift of pump (m)	Total installed power of pumping station (kw)
				Model no.	Q'ty (unit)			
Chaobaihe River		Raising the water level of open channels used for transmission of water; partial farmland drainage in Baodi County during the rainy season	50	18CJ-63	7	10.1	6.3	6 300
Erwang-zhuang pumping stations group	Erwang-zhuang under drain	Raising the water level from the upstream open channel to transport water to Yixingbu Pump Station; supplying water for Erwang-zhuang reservoir	35	1400ZLQ6-7	10	5.8	7	6 300
	Erwang-zhuang open channel pumping station	Raising the water level from the open channel to transport water to Dazhang-zhuang pumping station	30	18CJB-34	5	9.92	3.4	3 150
	Water diversion from Luanhe River to Tanggu District	Raising the level of water from the open channel to transport water to Tanggu District	3.0	24SA-10A	6	0.75	39	2 280
	Water diversion from Luanhe River to Hangu District	Raising the water level from the open channel to transport water to Hangu District	0.35	500S-22 350S-16	2 2	0.56 0.35	22 16	520
	Water diversion from Luanhe River to the development zone	Raising the water level from the open channel to transport water to Tianjin Economic and Technical Development Zone	1.12	500S-13 500S-35	2 3	0.56	13 35	1 060
	Water diversion from Luanhe River to Tianjin	Raising the water level from the open channel to supply water to Tianjin Polyester Engineering; standby water source for important users such as Dagang oil field	1.1	350S-75	4	0.37	75	1 600
	Water diversion from Luanhe River to Dagang District	Raising the water level from the open channel to supply water for large enterprises such as Dagang oil field, and domestic water demand in Dagang District	0.9	14SA-10B	5	0.3	48	1 300
	Water diversion from Luanhe River to Yang	Raising the water level from the open channel to transport water to Wuqing District and Yuxian Garden Economic and Technical Development Zone	0.97	500S-35A	4	0.485	27	880
Dazhang-zhuang		Raising the water level from the open channel to transport water to Haihe River; supplying water to Yixingbu pumping station during repairs; draining water in some areas during the rainy season	30	18CJ-63	5	10.1	6.3	4 500
Yixingbu pumping station (PS)	PS 1	Raising the water level of fore bay 1 to transport water to Xinkaihe water plant in treatment-phase 1; to transport water to the presedimentation pond in Hexi	19.1	32SA-10 32SA-19D 32SA-19B 32SA-19	10 2 2 4	1.4 1.05 1.3 1.5	48.5 13 20 29	13 820
	PS 2	Raising the water level in fore bay 2 to transport water to the water plant in treatment-phase 2	12.7	XJ48-18 XY44-20116 32SA-190	2 1 3	3.7 3 1.06	23 43.5 13	5 060

Table 3. Main technical parameters of the water diversion project from the Yellow River to Qingdao City

Name	Design flow of pumping station (m^3/s)		Design net delivery lift pumping station (m)			Model no.	Engine sets (units)	Design flow of single pump (m^3/s)	Total installed power of pumping station (kw)
	Design	Increased	Design	Max.	Min.				
Dayuzhuang	45.0	53.5	5.36	6.26	2.80	2000ZLB-5 900ZLB-4A	6 2	12.30 3.28	6 800
Songzhuang	34.5	38.0	8.71	10.03	7.79	12CJ-100 26HB-40	7 2	5.30 0.90	5 440
Wangru pumping station	29.5	32.5	10.05	12.05	8.63	1.6HL-50A 900HLB-10	6 2	7.00 1.87	5 420
Tingkou	26.0	28.6	6.78	6.81	4.16	18CJ-70	4	8.30	3 600
Jihongtan	23.0	33.1	7.98	11.78	3.37	1.6HL-50B 900HD-11.5	5 2	7.00 2.06	4 600

Table 4. Main technical parameters of the water diversion project from the Yellow River to Shanxi

	First pumping station in the general main line	Second pumping station in the general main line	Third pumping station in the general main line	First pumping station in the south main line	Second pumping station in the south main line	Total
Lift (m)	142	142	80	140	140	644
Flow rate (m^3/s)	48	48	48	25.8	25.8	
Installed power (kw)	120 000	120 000	60 000	72 000	72 000	444 000
Engine set (unit)	10	10	10	6	6	42

Table 5. Main technical parameters of the water diversion project from Dongjiang to Shenzhen

		Taiyuan	Lianhu Lake	Qiling	Jinhu Lake
Model no.		2.6ZLQ20-9.5	2600VZKNM	2600HTEXJ	2600HTEXJ
Speed rate		660	545	302	302
Type		VAFP†	VMFP‡		
Manufacturer		Gaoyou Pump Factory	Shangsha Pump Works Co. EBARA	Shenyang Water Pump Factory ANDRITZ	Shenyang Water Pump Factory ANDRITZ
Lift (m)	Max. lift	11.05	14	27.6	27.6
	Design lift	9.75	13	26.6	26.6
	Min. lift	2.6	7.5	22.3	21.2
Design flow rate (m^3/s)		20	16.7	12	15
Design point efficiency (%)		88	88	90	90
Rotational speed	Synchronous-speed	---	250 r/min	250 r/min	250 r/min
	Asynchronous-speed	213/186 r/min	245 r/min	245 r/min	245 r/min
Min. submergence depth (m)		-2.65	-6	-6	-6
Unit	Working pumps	5	6	6	6
	Emergency pumps	1	2	2	2
Motor power		2 006 kw	3 000 kw	5 000 kw	5 000 kw

† Vertical axial-flow pump. ‡ Vertical mixed-flow pump.

3. Pumping station modernization

Because the pumping station is an important component of the irrigation system, any upgrading of irrigation systems includes pumping station modernization: Equipping pumping stations with advanced equipment, reconstructing pumping stations with advanced modern technology and managing pumping stations with advanced modern management concepts.

The next sections introduce new technology, equipment, materials and achievements related to pumping stations in recent years.

3.1 Vertical mixed-flow pump (VMFP)

Currently, Qiling Pumping Station and Jinhu Lake Pumping Station use the world's biggest VMFPs in the reconstruction project for supplying water from Dongjiang to Shenzhen. The VMFP has the comprehensive advantage of high efficiency and excellent cavitation resistance. The new extractable structure of its rotor facilitates installation and repair. The dome improves the efficiency of the pump by minimizing the impact loss of transmitter substance when passing the pump exit. The electromotor for the pump is the biggest whole-lift vertical motor found in China today.

3.2 Vertical axial-flow pump (VAFP)

The VAFP is a pump suitable for pumping stations with low lift. Its usual inclination angles are 15°, 30° and 45°; we can choose different angles according to different lift. There are many low-lift pumping stations in irrigation projects in China, especially in the irrigation projects in Taihu Basin. There are a number of pumping stations with lift lower than 3 m in urban flood control projects in Jiangsu Province and Shanghai. The water level difference between the upper course and lower reaches of these pumping stations is very small, with smooth flow passage, small excavation depth and good water power, aspects that suit the VAFP.

The designed total flow rate of Taipu River pumping station is 300 m^3/s. After comparing the technological and economic performance of a number of pumping units, six VAFP units with 15° inclination angle and 50 m^3/s of single pump flow rate were selected. The diameter of the blade and rotational speed of the VAFP is respectively 4.1 m and 73 r/min. Due to the very low rotational speed, the transmission of the gear deceleration box is used. The power and rotation of the motor is respectively 1 600 kw and 1 000 r/min. The transmission power of the gear deceleration box is 1 600 kw, and the transmission ratio is i = 13.7; the box is a parallel gear box with two stages.

3.3 New free side-dump flap gate (or energy-saving irrigation and drainage arching-resistant valve)

The current design of this valve breaks through the conventional structural design of valves. It changes the valve plate from the swing type to the free side-dump type with which resistance is very small. This valve, developed by Hunan Liwei Hydraulic Equipment Co, Ltd., is a new energy-saving cut-out flow device used for pipes in pumping stations. It has passed production appraisal by the Ministry of Water Resources, and its patent holder and originator is Vice-Chief Engineer Zhang Yi.

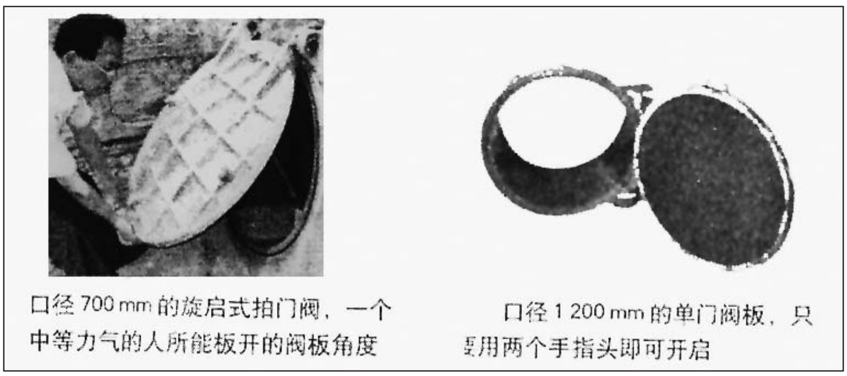

Plate 1. Valves with former swing-type flap gate (left) and the new free side-dump flap gate (right)

3.4 Large calibre PCCP pipe

The installation of the first batch of PCCP pipes in the first phase of the Huinan-zhuang to Daning PCCP Pipeline Project under the Beijing Emergency Water Supply Project in the South-to-North Water Diversion Project has been completed; thus the project is entering the full-scale installation phase. The whole project will be completed in 2007.

Technology for producing and using PCCP pipes (4 m diameter) has been developed; the design, production, transportation and installation of these pipes remain unprecedented in China. The design of the PCCP pipeline materials has surpassed the design standard of the American Water Works Association, and many of the design parameters, such as interface material, cushion rubber specification, cathodic protection and external corrosion prevention are higher than the present national standard.

The Huinan-zhuang to Daning PCCP Pipeline Project under the Beijing to Shijiazhuang Section in the South-to-North Water Diversion is 56.409 km (single direction length is about 112 km), which is 70 percent of the length of the general main channel in the Beijing Section. It is an important part of the middle line of the South-to-North Water Diversion Project, Beijing Section Project. It is also the key project for ensuring the whole Beijing to Shijiazhuang Section is completed in 2008.

3.5 Test benches

In 2005, the China Institute of Water Resources and Hydropower Research constructed three hydromechanical test benches, a sand slurry abrasion tester and a cavitation tester in its laboratory in Daxing. These test benches are equipped with high-accuracy testing and original position measuring systems, data acquisition and processing systems and an advanced PLC test operation system. The TP1, TP2 and TP3 are equipped with high-powered kinetic pumps, high pressure-resistant and corrosion-resistant steel pipeline systems, valves, electrical flow meters, tail tanks, pressure tanks, modelling units and dynamometer electric motors and auxiliary equipment.

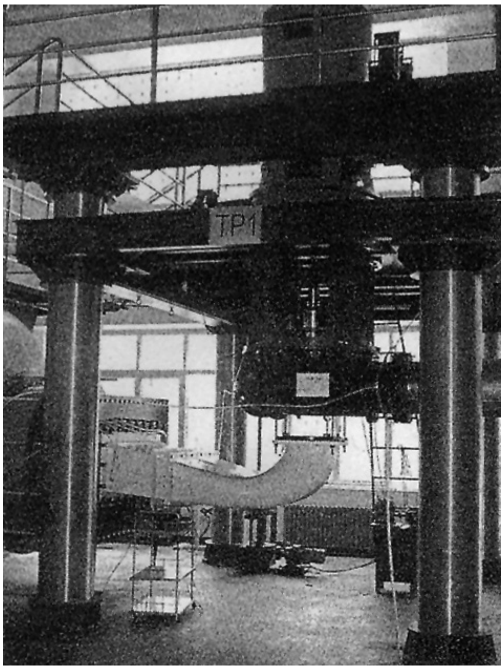

Plate 2. Hydromechanical test bench

The major performance parameters of the three test benches are given in Table 6. The composite error of the test benches in efficiency tests was ±0.2 percent. They are the only neutral test benches which are able to pass the contrast, inspection and acceptance tests of the machines both at home and abroad. The test precision and stability of the benches meet IEC- and GB-related standards.

3.6 South-to-North Water Diversion Project (Tianjin) water pump test bench

A water pump test bench has passed the technical appraisal organized by the Ministry of Water Resources. The composite error of the bench was ±0.3 percent in the efficiency test; its random error was ±0.1 percent. Its test parameters have passed the National Metrology Authentication and can provide sound hydraulic mechanical test data.

Major technical parameters of the test bench

Highest lift	30 m
Highest flow rate	1 000 liter/s
Motor power	160 kw (DC speed adjusting)
Test rotation	0–2 000 r/min
Motor power of the auxiliary pump	280 kw (frequency–conversion speed adjusting)
Capacity of discharge tank	70 m^3
Capacity of intake tank	35 m^3
Diameter of circulation pipeline	500 mm
Dischargeable capacity of the hydropower circulation system	≥10 m^3
Bench composite accuracy	≤±0.30%
Diameter of the test blade	250–460 mm

Table 6. Major performance parameters of the benches

Item	TP1 test bench	TP2 test bench	TP3 test bench
Highest water head	Hm = 150 m	Hm = 20 m (Hm = 80 m)	Hm = 60 m
Flow rate range	Qm = 0–2.2 m^3/s	Qm = 0–1.6 m^3/s	Qm = 0–1.0 m^3/s
Dynamometer motor	Pe = 540 kw	Pe = 300 kw	Pe = 300 kw
Rotation speed of dynamometer motor	nm = 0–2 600 r/min	nm = 0–3 000 r/min	nm = 0–3 000 r/min
Main kinetic pump	24SA-10(2台)	32SA-19(20SH-9)	28SA-10A
DC motor of main kinetic pump	N = 724 kw × 2(台)	N = 593 kw	N = 593 kw
Rotation speed of main kinetic pump	n = 0–1 200 r/min	n = 0–1 200 r/min	n = 0–1 200 r/min
Test model runner diameter range	D1 = 250–500 mm	D1 = 250–500 mm	D1 = 250–500 mm

Functions of the test bench

- It can be applied to test various low-lift, high-flow rate pump models and units.
- It is applicable for modelling blades with a diameter of 250 to 460 mm.
- It can be used to test axial-flow, radial-flow, mixed-flow and VAFP models and units.
- It can be installed with vertical axis, cross-axis, and slantways axis pump models and units.
- It can be used to test the performance of pumps such as efficiency, cavitation, runaway, water pressure pulse, noise, vibration.
- It can be used to test the closed-style hydromechanical pump.
- It can be used to test the open-style hydromechanical pump. The highest test lift is 4 m, and there is enough free water surface from the upper course to lower reaches.

- It can be used to observe the characteristics of cavitation, i.e. observe the flow status in the inlet and outlet.
- It can be used to rate the original position of all kinds of pressure and sensors.
- The length of the working section is as long as 12 m, and can be adjusted freely according to pump tests.

3.7 Optimum efficiency parameters of the VAFP

Table 7. Optimum efficiency parameters of the VAFP (D = 300 mm, n = 1 450 r/min)

Model no.	Blade angle ϕ/(*)	Flow rate Q/L/s	Lift H/m	Efficiency η/%	Average efficiency η/%	Weighted average utility η/%	Cavitation specific-speed rotation C	Specific-speed rotation ns	Nominal specific-speed rotation
	4	380.59	10.053	85.85			856	578	
	2	363.35	9.797	85.84			901	576	
JMT-08-9.5	0	347.17	9.518	85.19	85.08	85.12	956	575	550
	-2	332.65	9.162	85.51			1 007	580	
	-4	326.88	8.361	84.02			1 077	615	
	4	401.69	9.308	84.82			940	629	
	2	376.67	9.288	84.96			971	610	
JMT-03-8.5	0	362.84	8.788	84.71	84.41	84.45	1 004	625	600
	-2	351.58	8.363	84.50			1 006	638	
	-4	329.06	8.256	83.06			1 031	632	
	4	412.86	7.680	84.63			931	737	
	2	386.48	7.527	85.15			983	724	
JMT-02-7.5	0	367.50	7.262	85.60	85.12	85.11	1 010	725	700
	-2	358.30	6.737	85.22			1 045	758	
	-4	337.12	6.549	84.99			1 162	751	
	4	392.64	7.130	86.05			863	760	
JMT-20-6.5	2	381.47	6.678	85.58			926	796	
	0	365.81	6.430	85.29	85.44	85.46	1 008	793	800
	-2	345.32	6.408	85.20			1 089	772	
	-4	328.89	5.989	85.06			1 398	793	
	4	414.78	6.297	86.16			940	857	
	2	396.29	6.189	85.91			977	854	
JMT-19-6.0	0	374.05	6.219	85.44	85.50	85.54	1 019	822	850
	-2	357.17	5.783	85.13			1 157	848	
	-4	341.72	5.643	84.87			1 258	845	
	4	444.22	5.218	86.35			918	1 022	
	2	416.18	5.187	85.84			935	993	
JMT-06-4.5	0	401.64	4.800	85.72	85.62	85.56	1 002	1 034	1 000
	-2	377.20	4.804	85.46			1 032	1 002	
	-4	357.31	4.604	85.27			1 154	1 007	
	-6	332.17	4.599	85.10				971	
	4	397.23	4.183	83.77			957	1 140	
JMT-0.7-3.5	2	384.34	3.980	83.89			1 126	1 235	
	0	370.33	3.283	83.69	83.42	83.49	1 278	1 321	1 250
	-2	326.17	3.278	83.48			1 371	1 241	
	-4	282.04	3.571	82.28			1 294	1 082	
	4	473.62	3.179	74.29				1 530	
	2	437.18	3.144	75.39				1 482	
JMT-10B-2.5	0	414.03	2.655	75.33	75.19	75.11		1 637	1 600
	-2	378.55	2.639	75.64				1 573	
	-4	354.64	2.251	75.29				1 715	

Table 8. Optimum efficiency parameters of four other tested axial-flow pumps (D = 300 mm, n = 1 450 r/min)

Model no.	Blade angle ϕ/(*)	Flow rate Q/L/s	Lift H/m	Efficiency η/%	Average efficiency η/%	Weighted average utility η/%	Cavitation specific-speed rotation C	Specific-speed rotation ns	Nominal specific-speed rotation
TJ04-ZL-01C	4 2 0 -2 -4	356.62 368.48 380.33 402.02 417.86	4.597 4.995 5.209 5.511 5.917	83.51 83.56 83.64 83.22 84.34	83.65	83.66	1 119 1 003 907 855 802	1 008 962 978 933 902	950
TJ04-ZL-04	4 2 0 -2 -4	302.29 325.47 343.72 359.82 376.16	5.933 5.983 6.234 6.652 7.020	84.05 84.10 84.29 84.94 84.77	84.43	84.45	1 301 1 228 1 087 969 924	765 789 786 767 753	750
TJ04-ZL-05	4 2 0 -2 -4	329.26 347.29 366.99 378.02 401.96	4.731 4.974 5.287 5.913 6.096	81.84 83.21 83.34 83.55 84.40	83.27	83.32	1 358 1 269 1 160 1 034 994	948 936 920 858 865	850
TJ04-ZL-09	4 2 0 -2 -4	348.87 364.75 389.52 423.81 457.85	2.017 2.468 2.654 2.903 3.175	75.30 75.38 76.29 74.86 74.69	75.30	75.27		1 847 1 623 1 589 1 549 1 506	1 500

3.8 Current pumping station standards (under editing)

Table 9. Current pumping station standards (under editing)

Title	No.	Printed volumes
Design code for pumping station	GB/T50265-97	40 200 (105 000)
Construction code for pumping station	SL234-1999	5 100
Code of practice for technical renovation of pumping station	SL254-2000	8 100 (15 000)
Code of practice for technical management of pumping station	SL255-2000	8 100 (10 300)
Code of practice for safety appraisal of pumping station	SL316-2005	5 800
Installation and acceptance specification for pumping station	SL317-2005	8 000 (20 790)
Specification for design of rain-water pumping station	DBJ08-22-91	Printed by Shanghai Construction Commission
Specification for design of sewage pumping station	DBJ08-23-91	Printed by Shanghai Construction Commission
Criteria of construction of urban drainage pumping station in Tianjin	DB29-87-2004	Printed by Tianjin Construction Commission
Technical specification for maintenance of sewerage pipelines and channels and pumping station in city and town	CJJ/T68-96	2 300
Technical specification for vibration isolation of water pump	CECS59:94	Printed by China Association for Engineering Construction Standardization

Table 9. *(continued)*

Title	No.	Printed volumes
Technical terminology for rural water conservancy	SL56-2005	5 100 (7 450)
Code for model pump acceptance tests with sediment water	SL141-2006	(1 600)
Code for model pump and unit model acceptance tests	Under editing, admendment of SL140-97	(1 600)
Code of practice for updating renovation technology of pumping station	Under editing	

Notes:

1. *Design code for pumping station* (GB/T50265-97) is the updated edition of the *Design code for pumping station*, *design fascicule* (SD204-86).
2. *Installation and acceptance specification for pumping station* (SL317-2005) is a combination of *Code for technology of pumping station, installation fascicule* (SD204-86) and *Design code for pumping station, acceptance test fascicule* (SD204-86).
3. *Technical terminology for rural water conservancy* (SL56-2005) is a combination of *Engineering terminology for pumping station, driven well, overhead irrigation, and drip irrigation* (SDJ231-87), and amendment of *Technical terminology for farm land* (SL56-93).
4. The numbers in parentheses are the number of books at the first printing.

4. Pumping station development

Tables 10 and 11 respectively list the parameters for new pumping stations in the South-to-North Water Diversion Project (East Line, Jiangsu Section) and modifications for pumping stations in the four central provinces.

Table 10. Parameters for new pumping station projects in the South-to-North Water Diversion Project (East Line, Jiangsu Section)

Name	Design scale (m^3/s)	Type	Design lift/m	Single pump flow rate (m^3/s)	Installed power/ kw	Installed units
Baoying Station	100	Vertical mixed-flow pump	7.60	33.4	3 400	4
Huai'an Station No. 4	100	Bulb radial-flow pump	4.15	33.4	2 240	4
Lake Jinhu Station	150	Bulb radial-flow pump	2.35	37.5	2 240	5
Huaiyin Station No. 3	100	Bulb radial-flow pump	4.28	34.0	2 240	4
Hongze Station	150	Vertical axial-flow pump	6.00	30.0	3 000	6
Siyang Station	164	Vertical axial-flow pump	6.30	33.0	3 000	6
Sihong Station	120	Bulb radial-flow pump	3.70	30.0	3 000	5
Liulaojian Station No. 2	80	Bulb radial-flow pump	3.70	31.5	2 000	4
Qiaoning Station No. 2	60	Vertical mixed-flow pump	9.20	30.0	4 200	3
Zaohe River Station No. 2	75	Vertical axial-flow pump	4.65	37.5	2 800	2
Pi Zhou Station	100	Bulb radial-flow pump	3.20	34.0	2 500	4
Liushanzhuang Station	125	Vertical axial-flow pump	5.73	31.5	2 800	5
Tai'erzhuang Station	125	Vertical axial-flow pump	4.53	25.0	2 000	6
Jietai Station	125	Vertical axial-flow pump	5.84	31.5	2 800	5
Wangnianzha Station	125	Vertical axial-flow pump	5.49	31.5	2 650	5
Linjiaba Station	75	Bulb radial-flow pump	2.40	25.0	1 250	4
Hanzhuang Station	125	Bulb radial-flow pump	4.15	31.5	2 000	5
Erjiba Station	125	Bulb radial-flow pump	3.21	31.5	1 850	5
Changgou Station	100	Vertical axial-flow pump	4.06	33.5	2 240	4
Denglou Station	100	Vertical axial-flow pump	3.97	33.5	2 240	4
Baliwan Station	100	Vertical axial-flow pump	5.40	25.0	2 400	5

Table 11. Modification parameters for pumping stations in the four central provinces

Prov.	No. of rebuilt stations	Modification planning & design parameters				No. of pumping stations modified			
		Drainage standard (years/ event)	Total installed power (kw)	Installed units	Design flow rate (m^3/s)	Removed and rebuilt	Extended	Modified	Total
Hubei	60	10	49.63	901	5 365	3	1	98	102
Hunan	29	10	28.70	1 037	2 493	5	0	150	155
Jiangxi	17	5–10	14.33	776	1 590	21	0	105	126
Anhwei	33	5–10	18.03	736	1 983	20	16	59	95
Total	**139**		**110.69**	**3 450**	**11 421**	**49**	**17**	**412**	**478**

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The complexity of PLC-based canal automation

Charles M. Burt[1]

1. Introduction

In the western United States, "modernization" is a multidimensional process that focuses on improving canal and pipeline controls rather than physical modifications *per se* such as canal lining or simple rehabilitation. The complexity of this process requires strict attention to detail, because even small details can create problems that set modernization projects back several years.

Ideally, irrigation projects — in the context of modernization — make a gradual shift in technology that allows operators, managers and maintenance staff ample time to become accustomed to new procedures. This involves several decades of measured improvements that start with a comprehensive vision for the project. To ensure success, a modernization plan should include the following items:

- An excellent examination of the present capabilities and limitations of the water delivery system.
- A definition of service objectives.
- A strategic plan to modernize structures and the delivery system to achieve the desired objectives. The plan should include a holistic view of the project that involves options such as pumping, regulating reservoirs, communications, new delivery service criteria, recirculation and numerous other elements.

In this ideal situation, once key participants of the modernization project have understood and agreed on the plan and its objectives, physical improvements begin. This also requires careful execution, beginning with the simplest structures and moving upward in scale. The field implementation schedule might be:

- Simple hydraulic structures are used first. These include long-crested weirs, ITRC flap gates and AMIL gates.
- Communications between staff, and between staff and strategic monitoring sites, improve.
- Regulating reservoirs and recirculation systems are installed.
- Effective flow rate control is established at the heads of canals and unrecoverable spill is minimized
- Water users' associations are developed and strengthened.
- Water is limited and sold volumetrically.

This presentation relates some of the experiences of the Irrigation Training and Research Centre (ITRC) of California Polytechnic State University, which has assisted with the modernization of about 200 irrigation projects (called "districts" in the western United States) in the United States and other countries. It is clear that slow yet scheduled and deliberate changes generally have the greatest chance of success. Structural changes are usually also accompanied by operational changes and even simple combinations of changes can be problematic in effective implementation, therefore requiring time for success. The reasons for this are numerous — the need for attention to detail is universal.

If there is a gradual shift in hardware and operations and maintenance requirements — plus adequate budgets, training, determined managers, service-oriented staff and top-level support — there is adequate time to learn the details and find solutions to problems.

2. PLCs and SCADA in irrigation districts

But many projects need or desire a rapid shift to high technology. A sudden and unprepared shift to high-end control systems that use Supervisory Control and Data Acquisition (SCADA) and Programmable Logic

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Controllers (PLCs) can be the equivalent of learning to swim by jumping straight into the deep end of the pool — without mastering the initial steps of the process, the ultimate goal may be too challenging to attain.

There is absolutely no doubt that numerous irrigation control situations could theoretically receive maximum benefit if PLCs were used. The ITRC has designed and helped to implement dozens of successful systems. But each of these systems has been approached with extreme caution, and each one has had numerous unexpected problems. One of our mottos is: "The devil is truly in the details".

Up to this point, I have used the terms "SCADA" and "PLCs" loosely. The use of PLCs and SCADA in an irrigation project can mean many things. Some variations are shown in Table 1.

It is common for an irrigation district SCADA system to contain a combination of the cases in Table 1. For example, a district may have several PLC-automated sites, plus some sites where PLCs are used with remote manual operation, plus a variety of sites that only need monitoring and perhaps alarms.

Table 1. Variations between and within SCADA/PLC systems

Case	Basic function	Frequency of sensor monitoring	Frequency of data transmission to office
1 Monitor	Alarm for high/low values	Continuous	Only if alarm condition exists
2 Monitor	Alarm for specific values such as height, position, temperature	As often as once/second, as seldom as once/15 min.	Only if alarm condition exists
3 Monitor	Remote monitoring of specific values such as height, position, temperature. No alarming	As often as once/second, and as seldom as once/day	For river basins, often a few times/day. For irrigation districts, often once/minute
4 Monitor	Cases (2) + (3)	1/sec – 1/day	Once/day remote monitoring can be over-ridden by an alarm exception at any time
5 Monitor plus manual	Case (4) plus remote manual control of an actuator	1/sec – 1/15 min.	1/30 sec – 1/30 min. Slower than 1/min is outdated and cumbersome for operators
6 Monitor plus Automation	Case (5) plus remote changing of target values for local, independent automation	1/sec – 1/15 min. With modern automation, 1/sec or more frequent is common	1/30 sec – 1/30 min. Slower than 1/min is outdated and cumbersome for operators
7* Monitor plus Automation	Case (6) plus feed-forward between local controllers	1/sec – 1/15 min. With modern automation, 1/sec or more frequent is common	1/30 sec – 1/30 min. Slower than 1/min will often not work with feed-forward. *This is rarely found in an irrigation district*
8* Monitor plus Automation	Case (4) plus centralized computation of gate/pump movements	1/sec – 1/15 min. With modern automation, 1/sec or more frequent is common	1/sec – 1/15 min. *This is rarely found in an irrigation district*

* Forms of automation with few examples of sustained success in irrigation districts.

An abbreviated flow chart for the process of building a SCADA/PLC system for Case 6 in Table 1 is given in Figure 1. Within each of the action blocks are numerous steps. Within the box labelled "Perform Specific Field Tests", for example, ITRC has several pages of procedures. Likewise, for checking the wiring and calibration of the field PLCs alone we have 12 pages of flow charts.

A key factor is that ITRC expects to encounter problems and makes every effort to ensure that the customers also anticipate problems. If there is sufficient budget, well-trained and motivated staff, an excellent technical team, high-quality commercial equipment, good planning, patience and a "can-do" attitude by all team members then these problems can usually be solved quickly. But with PLC-based control, a single problem can completely stop a project if it is not solved.

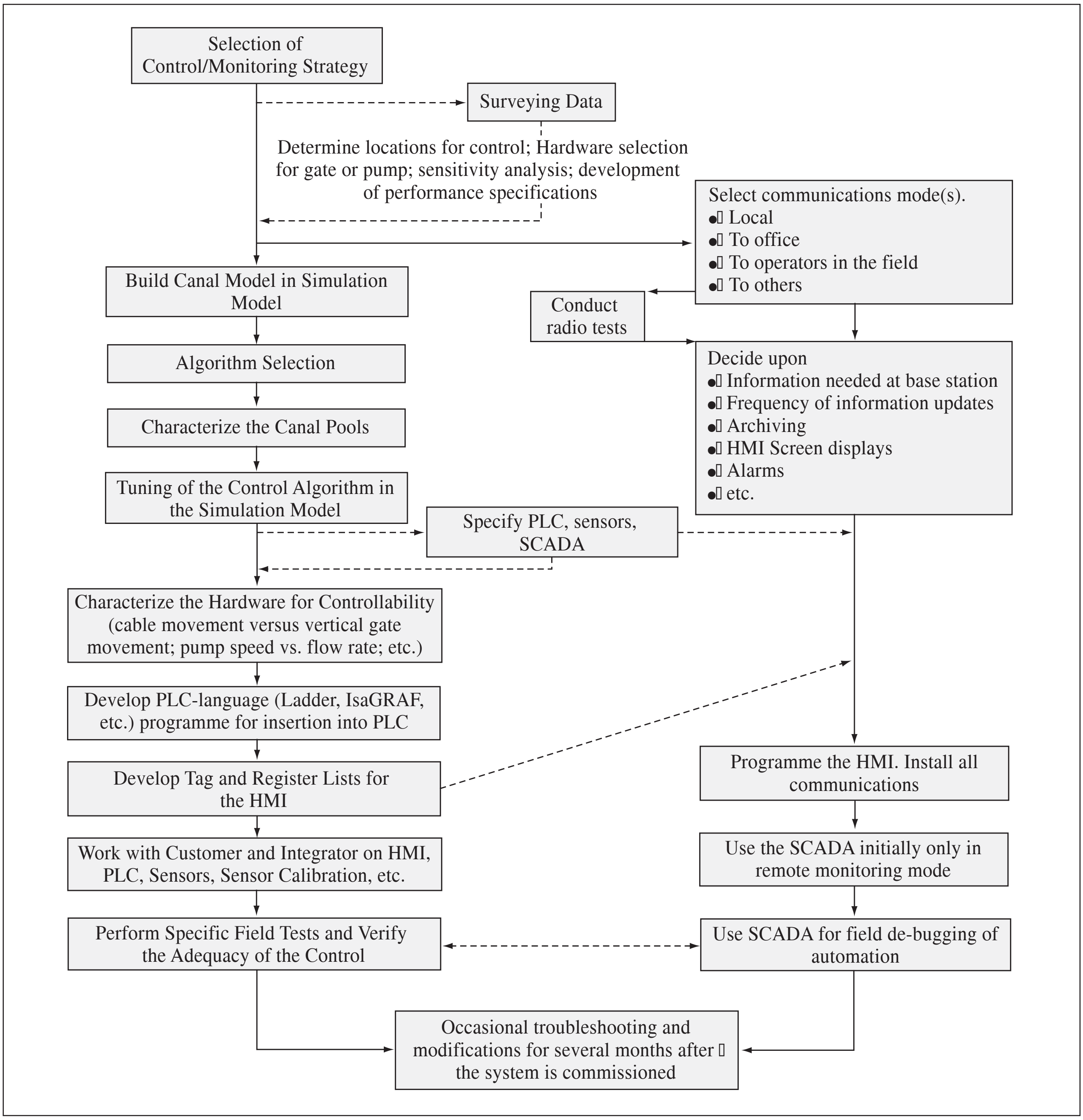

Figure 1. Outline for design and implementation of a Case 6 SCADA/PLC system

ITRC has noted that failed PLC-based modernization schemes are typically accompanied by research-on:

- Developing hydraulic simulation models.
- Developing new water level sensors.
- Developing new gate actuators.
- Developing any new technique or device that is already available commercially and that has a proven track record.

Any PLC-based system, even one that uses time-tested, off-the-shelf hardware, will be complex and challenging. Burdening a modernization project with attempts to develop new techniques and equipment while a new system is still being implemented will almost certainly create more problems than it solves. This is not to say that new techniques should not be tried and tested — but only once the existing system is up and running well. Simply getting good equipment and well-tested techniques to work properly is enough of a challenge to stretch the time and resources of the project team.

3. Emphasizing the team

People who are experts in PLCs may not be experts in communications and they generally know very little about canal hydraulics. People who may understand canal hydraulics may know very little about unsteady flow control and do not understand strategic vision. In other words, a project usually needs an excellent and specialized team. Putting out a new SCADA/PLC irrigation project for engineering bids from large companies has traditionally been a recipe for disaster in the United States.

In the United States, many specialized companies provide "integration" services that typically encompass the installation and programming of PLC-based automation. However, these companies almost never have experience with irrigation projects. The control logic used in irrigation canals is completely different in nature from the standard control logic that is used *inter alia* in the oil industry, processing plants and wastewater treatment facilities. The types of gate actuators, sensors, etc. are also different. Therefore, most successful projects have utilized small integrator companies that specialize in irrigation project SCADA/PLC applications. Even with these companies, there are challenges and there must be excellent written specifications, accompanied by quality control checks.

When ITRC is involved in an automation project, there can be many different ways in which tasks are allocated. A typical task allocation is:

ITRC is always responsible for providing:

- The overall automation strategy for the project.
- The specific control requirements for each structure. This includes options such as flow rate control, upstream water level control, feed-forward control of various types, downstream control of various types, etc.
- The SCADA specifications for the integrator to bid on.
- The control code for the proposed control logic. We now provide this in ISaGRAF[2] control language that can be directly inserted into the PLCs. This minimizes the bother of leaving the programming to the integrators and reviewing their work to correct errors.
- Troubleshooting and field verification.

The integrator is generally responsible for:

- Sensor installation, conduits, wiring, etc.
- PLC wiring and labelling.
- Radios, repeaters and other communication requirements.
- Alarm autodialing.
- Human–Machine Interface (HMI) design.

The line that distinguishes the ITRC-provided ISaGRAF control code and the integrator's work is the assigned registers for each site. ITRC provides the integrator with a full explanation of the tags and the assigned registers and their associated recommended values that need to be designed and displayed in HMI. The integrator ensures that the ITRC-listed HMI variables that are assigned with the associated registers can be either inputted through or displayed in HMI either through radio or another communications mode.

[2] ISaGRAF is a control software environment that enables the creation of local or distributed control systems. It offers a combination of a highly portable and robust control engine and an intuitive application development environment.

4. Conclusion

There are hundreds of details in PLC-based irrigation control schemes that involve communications, modelling, proper selection of the control scheme, the details of the control logic, programming, hardware selection and HMI design. When designing PLC-based automation in an irrigation project, ITRC attempts to use excellent, commercially available hardware and to thoroughly specify equipment and performance. We attempt to guide customers to qualified integrators and we provide complete programmes for the PLC.

In spite of years of experience, problems always occur. However, if they are anticipated and if excellent hardware is used, they can be surmounted. To minimize the challenges, new attempts at PLC-based automation should focus on simply getting excellent industrial equipment to work properly rather than trying to also introduce new hardware such as sensors and communications. Once the whole complicated process is thoroughly understood, attention can be paid to the development of new, specialized equipment and software that will fine-tune the process.

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Karnataka Neeravari Nigam Ltd. — a corporate model and growth engine in water resource development

D. Satya Murty[1]

1. Brief background of the company

Karnataka Neeravari Nigam Ltd. (KNNL) was incorporated on 9 December 1998 as a Public Limited Company under the Companies Act, 1956. The main objectives are time-bound completion of a number of prioritized major and medium irrigation projects, mainly in the Krishna Basin, that were chronically underfunded.

2. Rationale for establishing the company

- KNNL was established in 1998 to expedite completion of ongoing projects in Krishna Basin.
- It was formed as a Special Purpose Vehicle (SPV).
- Mobilization of internal and external resources as well as efficient and judicious use of funds. The authorized share capital is US$0.66 billion (3 000 *crores*).[2]
- Time-bound investment plan.
- Timely completion of projects.
- Better management and achievement of goals.
- Rapid decision-making to generate efficiency in the construction and administration of projects.

3. Main objectives of the company

- "Plan, investigate, estimate, build, operate and maintain irrigation projects and the works of the Command Area Development Authority (CADA) in any part of the State of Karnataka (excluding the Upper Krishna Project being built by the Krishna Bhagya Jala Nigam Limited)".
- Prepare detailed project reports and estimates of irrigation projects and build them after the Government of Karnataka (GoK) obtains necessary approval and sanctions the projects administratively.
- Resettle and rehabilitate people affected by the building of irrigation projects.
- Protect and improve the overall environment through appropriate measures, including treatment of the catchment areas of irrigation projects and afforestation.
- Adopt appropriate standards and specifications for the construction and maintenance of irrigation projects, draw up fresh standards/specifications, where necessary, and enforce modern quality assurance procedures.
- Promote schemes for flood control in the project areas.
- Promote schemes for navigation in the rivers where irrigation projects are being implemented and for leisure activities, fisheries, etc. in the waterbodies of these projects.
- Promote the adoption of modern irrigation methods and the use of new materials and technologies in building irrigation projects.
- Promote schemes for utilizing water from the irrigation projects built by the company.

The GoK has transferred 39 projects to KNNL for implementation (Figure 1).

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[2] 1 *crore*= ten million.

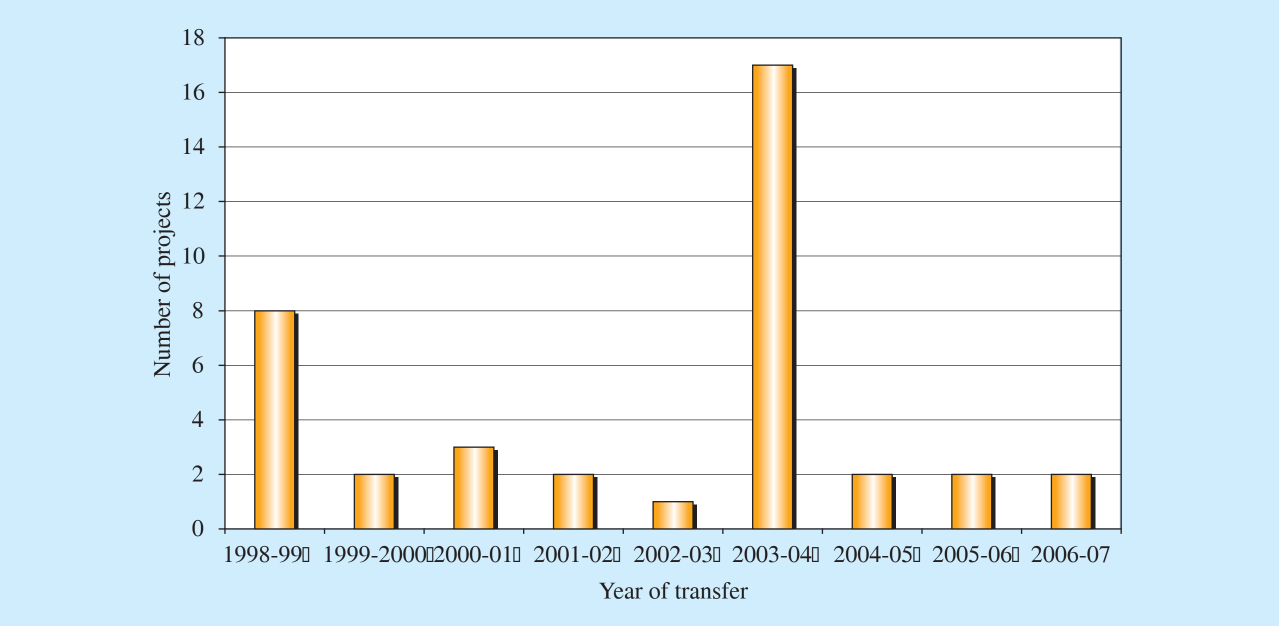

Figure 1. Number of projects transferred to the KNNL by the government (yearwise)

4. Projects completed during the KNNL period

Completed:

- Harinala Projects, 2005–2006
- Bennithora Projects, 2006–2007

Proposed to be completed:

- Ghataprabha Project, 2006–2007
- Malaprabha Project, 2006–2007
- Lower Mullamari Project, 2006–2007
- Markandeya Project, 2006–2007
- Gandorinala Project, 2006–2007
- Itagi Sasalwad, 2006–2007
- Basapur LIS, 2006–2007

5. Advantages and disadvantages

- Better management and rapid decision-making.
- Injecting professionalism.
- Swift implementation of projects.
- Resource mobilization (both internal and external) and disbursement.
- Timely completion of projects.
- Efficiency in construction and administration of projects.
- Timely payments of work bills to contractors.
- Review of projects by specialists and experienced engineers.
- Efficient monitoring of the progress of work and solving field problems.
- Unit-wise completion of projects under focused quality control of "Package & Turn Key projects".

- Integration and synchronization of all components of projects to enable the supply of water up to the field level and full realization of irrigation potential.
- Delay in the decision-making process.
- Delay in resolving technical issues.
- No close monitoring of progress.
- Delay in paying contractors' work bills.
- The land acquisition process is hampering rapid implementation.
- Rehabilitation and resettlement problems.
- Human resource problems.
- Shortfall in government funding of projects.
- Delay in clearances from Forest & Environment Ministries of the Government of India (GoI), the Central Water Commission and the Planning Commission

6. Human resources

There are 5 004 employees in the company (Table 1) out of which 4 986 employees are on deputation from the GoK.

Table 1. Company staff quotas

Category	Technical	Non-technical	Total
On deputation from GoK	1 006	3 980	4 986
On deputation from public sector enterprises	0	1	1
On contract	0	17	17
Total	**1 006**	**3 998**	**5 004**

7. Overall advantage of being a corporation

The rules and regulations for the management of public affairs are rigid and inflexible. Besides financial constraints, the government has to address various schemes, issues and projects that involve a consultative process with other departments. Accountability is diffused. Therefore completion of any project undertaken by the government takes a long time and delays are inevitable. The system is never geared to function in an enterprising manner.

The formation of a public enterprise mandated to carry out specific tasks, envisaged in its constitution, is one of the government's methods to impart efficiency in the execution of major activities in the public domain.

Such an enterprise is a legal entity incorporated under the corporate law legislated for the functioning of commercial enterprises. Unlike government units, the corporate body is focused on specific tasks and is accountable to the government for achieving objectives in a given time frame. The government, while maintaining control over the management of the enterprise, facilitates the corporate body by delegating power and authority to take decisions. The corporate body has functional autonomy to plan and execute the task through professional managers by laying down its own rules and regulations for day-to-day management. The government monitors the activities of the enterprise through its nominees on the governing body and a periodic review of performance. Government control is also enforced through directions seeking compliance to carry out (or otherwise) a particular agenda for which provision is made in the constitution of the enterprise.