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Irrigation Schedule Models For The Management Of Surface And Groundwater Resources In Erode District Tamilnadu

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ABSTRACT
The irrigated agriculture in the Erode region of Tamilnadu is characterized by huge water withdrawals from the Cauvery River. The vast infrastructure built for extensive irrigation, together with inappropriate drainage infrastructure, leads to a build-up of very shallow groundwater (GW) levels, followed by waterlogging and salt accumulation in the soil profile. Previous studies revealed deficits in the management and maintenance institutions, inappropriate and inflexible irrigation strategies, poor linkages between field level demands, and in the operation of the network. No flexible water management tool is currently in use that, by pre-conceiving mitigation strategies, would aim at reducing the current yield reductions. This study aimed to develop and introduce such a tool at the irrigation scheme level, illustrated at the example of the Water Users Association (WUA) in Erode (about 2,000 ha of farmland). The tool can support managerial decisions on optimization of water use, particularly under the deficiatary water supply predicted under climate change. Remote Sensing (RS) techniques were used in combination with real-time hydrological measurements (e.g., ponding experiments to estimate losses in canals) to assess the operational performance of the WUA. Delivery performance ratio (DPR), relative evapotranspiration (RET), depleted fraction (DF), drainage ratio (DR), overall consumed ratio (OCR), field application ratio (FAR) and conveyance ratio (CR) were used as performance indicators. Using the current and target values for FAR and CR, three improved irrigation efficiency scenarios were .Recharge to the aquifer was determined for these scenarios by the water balance approach. Spatial dynamics of GW levels and soil characteristics (factors that affect recharge) were represented by dividing the WUA into 'hydrological response units'.

Keywords: Irrigation Schedule Models, Surface, Groundwater Resources, Erode District, Tamilnadu

1. INTRODUCTION

1.1 Water For Irrigated Agriculture
By the year 2025, worldwide food production must grow by at least 40 % to meet the needs of a world population that will have increased by 33 % by then, and to satisfy the trends for improved nutrition (Bos et al., 2005). About 83 % of the expected 40 % increase in population (to 8.5 billion) is predicted to live in developing countries. In transition countries such as those in Central Asia and the Caucasus (CAC), climate change, specific characteristics and legacies of the past have caused vulnerability to food insecurity (Christmann et al., 2009; Wehrheim and Wiesmann, 2003). Yet the capacity of available resources and technologies to meet the growing demands for food, fuel and fiber, especially in developing countries, remains uncertain. The world's food production largely depends upon the availability of water resources, but these resources are finite. Ayars et al. (2006) warned that future scenarios predict a worldwide fresh irrigation water scarcity due to a) the competition among the different users (urban, industrial and environmental), and b) the increasing food, fuel and fiber demands resulting from the increase in population. Predictions also indicate an even higher water shortage in arid and semi-arid regions, where water is already a scarce commodity. The role of water as a social, economic, and life-sustaining commodity should be reflected in demand management procedures for coping with supply and be implemented through resource assessment and water conservation and reuse (UNCED, 2002).

1.2 Challenges Of Irrigated Agriculture In Tamil Nadu
Irrigated agriculture is one of the critical pillars of Tamil nadu economy. This sector contributes about 33 % of the country's gross domestic product (GDP) and employs 60 % of its labor force (Djalalov, 2001). Due to the arid to semi-arid climate, agriculture consumes 92 % of Tamil nadu total water use of 56 billion cubic meters (BCM).

Huge amounts of water are withdrawn from the CAUVERY and bhavanisagar (80 % of the total water use), the main sources of irrigation water supply. Nevertheless, since approximately the 1990's, the region frequently experiences insufficient water supply, particularly so in the downstream and middlestream reaches of the rivers (Olimjanov and Mamarasulov, 2006), which is attributed to low irrigation efficiency (Conrad, 2006). As 80% of erode water supply comes from neighboring countries, primarily via the Rivers CAUVERY and bhavanisagar , agriculture and agricultural policy in Tamil nadu also have significant international dimensions. Along with this, competition for water between the local water users has increased substantially (Abdullaev et al., 2008a).

1.3 Objective Of The Study

The main objective of this study is to establish and introduce a hydrological tool by integrating surface and sub-surface irrigation that is based on satellite remote sensing and hydrological models to support the managerial decisions at the water users' association level.
The specific research objectives are:

- Develop an irrigation scheduling model for CAUVERY Water Users Association (WUA) that is spatially and temporally highly detailed for improved system operation in the WUA (spatial resolution is to be achieved through developing an approach based on site- and soil-specific hydrological response units);
- Develop management scenarios of optimized system operation with the goal of maximizing the farmers' objectives under system- and water-resource limitations while minimizing impacts on the environment.

The conceptual framework to achieve these objectives is presented in the following section.

1.4 Development Of A Hydrological Tool

To develop a hydrological tool that operates at a high temporal and spatial resolution, CROPWAT model was used as a basis. CROPWAT can develop irrigation schedules at high temporal resolution. It can be used to develop optimal irrigation schedules considering both sufficient water supply and reduced supply. In the first case, the optimal schedule allows avoiding water stress, and in the second case, the impact of water stress on yield reduction can be minimized and the yield losses under reduced water supply can be quantified. It has a shortcoming, however, as it is not able to compute the contribution of capillary rise to crop water use. To fill this gap, the HYDRUS-1D model was used; it has been parameterized for ERODE and provides reliable quantifications of capillary rise (Forkutsa, 2006). We used HYDRUS-1D to compute capillary rise on a daily basis, and the values were introduced to CROPWAT.

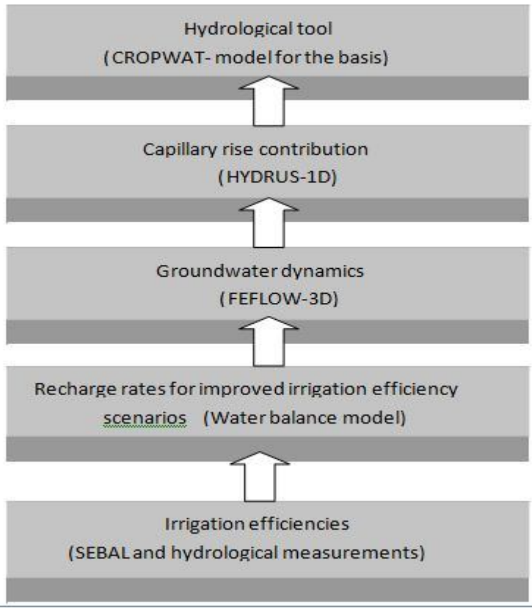

Figure. 1 Flow Chart

However, the GW levels are dynamic in nature and can vary significantly following surface water interventions. Therefore, the tool was further integrated with hydrological models to simulate improved irrigation efficiency scenarios. Remote sensing techniques (determination of actual and potential evapotranspiration using SEBAL) and real-time hydrological measurements (field experiments for application efficiency, rating curves for inflows and outflows from the WUA, ponding experiments for conveyance losses) were used to determine the overall irrigation efficiency of the WUA.(Figure.1)

1.5 Operational Performance In The Study Area

To assess the operational performance of the irrigation system in the study area in general and field and application ratios in particular, remote sensing techniques (Surface Energy Balance Algorithm for Land (SEBAL) for potential and actual evapotranspiration rates) were used in combination with real-time hydrological measurements (inflow and outflow from the study area, ponding experiments for conveyance ratio and field experiments for field application ratio). Delivery performance ratio (DPR), relative evapotranspiration (RET), depleted fraction (DF), drainage ratio (DR), overall consumed ratio (OCR), field application ratio (FAR) and conveyance ratio (CR) were selected as performance indicators.
The irrigation scenarios investigated here refer to improvements of the FAR and CR towards target values derived from the literature. Irrigation efficiency by definition is the product of the FAR and CR. Target values of FAR were taken from Bos and Nugteren (1990, 1974a)

and target values of CR were taken from Jurriens et al. (2001). By using the current and target values of FAR and CR, one baseline and three improved irrigation efficiency scenarios were developed:

- Scenario A: baseline business-as-usual (BAU),
- Scenario B: improving CR,
- Scenario C: raising FAR, and
- Scenario D: improving FAR and CR together.

1.6 Recharge Estimates And Development Of Hydrological Response Units

Irrigation efficiency strongly influences the recharge rates. Recharge rates in this study for the four irrigation efficiency scenarios were determined by the water balance approach under the assumption that the difference between gross and net irrigation requirements feeds the aquifer. However, recharge rates at field level depend on several factors, e.g., climatic conditions, soil texture, cropping pattern and GW levels. These factors can vary significantly in any irrigation canal command area. Thiessen polygons (on the available point data of GW wells and soil texture) were drawn in Arc GIS to capture the spatial variability of GW levels and soil texture, which determine the capillary rise and in turn, the water balance and hence the recharge. Satellite remote sensing was used for the land-use classification in the area. Areas of similar GW and soil texture in the WUA were defined as hydrological response units (HRUs).

1.7 Quantifying The Gw Dynamics

The spatial and temporal behavior of groundwater levels largely depends upon the recharge rates. The FEFLOW 3D model (Diersch, 2002a), which has successfully been tested for a number of benchmark examples in variable density flow, was selected for this study. FEFLOW uses recharge rates to simulate the GW dynamics on a daily basis. The daily changes in GW levels were simulated for four different irrigation efficiency scenarios.

1.8 Quantifying Capillary Rise And Optimizing Irrigation Schedule With Hydrological Tool

With the daily GW levels, the HYDRUS-1D model (Simunek et al., 2005) was used to compute the capillary rise contribution for the four efficiency scenarios and for key crops (cotton, wheat and vegetables). These values were then entered into the CROPWAT model. Capillary rise was introduced into the CROPWAT model through the *user defined irrigation* option to develop the various scenarios, e.g., develop the optimal irrigation schedule for cotton, wheat and vegetables under the BAU scenario, develop the optimal irrigation schedule for cotton for the above-mentioned irrigation efficiency scenarios, compare the current and flexible irrigation scheduling, derive the options for water saving (change in cropping plan, leaving marginal locations out or for alternative crops), and develop the strategies for situations with low water availability.

2. CONCEPTS AND MISCONCEPTIONS OF CONJUNCTIVE USE

In most climates around the world, precipitation, and consequently peak river discharge, occurs during a particular season of the year, whereas crop irrigation water requirements are at their greatest during periods of low rainfall when unregulated stream flows are significantly lower. For many irrigation systems, water supply is aligned with crop water requirements through the construction and management of dams which capture water during periods of high flow, enabling regulated releases to meet crop water requirements. However, the construction, operation and distribution of water from dams are inherently costly undertakings. Furthermore, dams and the associated distribution systems are commonly subject to high system losses through evaporation and leakage (though it is debateable whether the latter is actually detrimental given that it often contributes substantially to groundwater recharge), and they have social and ecological impacts upon communities and the environment in and on which they are built.

Conversely, under natural recharge regimes, groundwater storage requires no infrastructure, the aquifer serving as the natural distribution system. The point of irrigation, in a groundwater-fed irrigation command, is commonly opportunistically located close to the groundwater extraction point, which in turn is integrated into on-farm irrigation infrastructure. Under a sustainable extraction regime, groundwater of a suitable quality can provide a reliable source of water either as a sole supply of water, or to supplement alternative sources. Commonly, the large storage to annual use ratio typical of many regional aquifers means that the reliability of supply from groundwater is less affected by seasonal conditions than are surface water systems, and may indeed provide significant buffering against droughts. However, most intensively used groundwater systems (within the context of irrigation) are located in the semi-arid parts of the world and are characterised by relatively low annual recharge. Then the ratio of annual use to long term annual recharge becomes the predominant measure of sustainability for these systems, independent of aquifer storage. Whilst providing a large storage and natural distribution system, aquifers are, generally speaking, unable to capture a significant portion of runoff arising from large rainfall events. Aquifers therefore do not annually harvest water on a scale that justifies the construction and operation of centralised water delivery systems based on groundwater alone.

These specific characteristics of surface and groundwater resources have important implications for the optimal design and operation of irrigation systems. However the benefits and limitations are rarely fully considered in the

optimisation of system design. Rather supply design is normally focused upon one source of water, with conjunctive use often an 'after thought' and hence infrastructure and management responses are retro-fitted to existing arrangements.
Depending on the relative volumetric mix of the two resources, and the manner in which associated irrigation has been historically developed, the nature of conjunctive use at any one irrigation command will be significantly different. For example, management approaches must be different where ninety percent of the available water is from one of the two resources as compared to the situation where neither resource supplies a majority. Also subtly, groundwater can have three separate roles within a conjunctive management framework; it can be used as an alternative method to distribute water across irrigation commands; it can be used as a storage mechanism to smooth out the supply/demand balance either across seasonal patterns of water availability, or across decadal variability in climate.

At the general level the benefits attributed to optimising conjunctive use of surface and groundwater have been investigated over many years through theoretical modelling and studies of physical systems. These benefits take the form of:

- Economic gains
- Increases in productivity
- Energy savings
- Increased capacity to irrigate via larger areas
- Water resource efficiency
- Infrastructure optimisation

However, there are few published analyses of the actual socio-economic benefits that can be attributed to the implementation of conjunctive use management in specific irrigation commands. This is a major impediment to further communicating the positive messages regarding conjunctive use. However, an example of such studies includes Bredehoeft and Young (1983), who modelled a twofold increase in net benefit arising from conjunctive management. Another is the Agriculture and Rural Development Group, World Bank (2006), which reported a 26 percent increase in net farmer income, substantial energy savings, increased irrigation and substantial increase in irrigated crop area for Uttar Pradesh, India, as a result of conjunctive management of monsoon floodwaters in combination with a regional groundwater system.

3. ABOUT THE STUDY AREA

Erode District (previously known as Periyar District) is a district in the Kongu Nadu region (western part) of the state of Tamil Nadu, India. It was the largest district by area in the state before the Formation of Tirupur District and the headquarters of the district is Erode. It is divided into two revenue divisions namely Erode and Gobichettipalayam and further subdivided into 6 taluks. Periyar district was a part of Coimbatore District before its bifurcation on September 17, 1979 and was renamed as Erode District in 1996. As of 2011, the district had a population of 2,251,744 with a sex-ratio of 993 females for every 1,000 males, much above the national average of 929. The district is bounded by Chamarajanagar district of Karnataka to the north, and by Kaveri River to the east. Across the river lies Salem, Namakkal and Karur districts. Tirupur District lies immediately to the south, and Coimbatore and the Nilgiris district lie to the west. Erode District is landlocked and is situated at between 10 36" and 11 58" north latitude and between 76 49" and 77 58" east longitude. The district forms the meeting point of Western Ghats and Eastern Ghats separated by Bhavani River.

Fig 2 Western Ghats as seen from Gobichettipalayam

The district comprises a long undulating plain, sloping gently towards the Kaveri River in the south-east. Three major tributaries of river Kaveri, the Bhavani, Noyyal and Amaravati, run across the long stretch of mountains in the north. Palar River constitutes the boundary between Erode district and Karnataka in the north. The Bhavanisagar Dam and Kodiveri Dam provide storage facilities and numerous canals along with these rivers provide proper drainage and facilities for irrigation in the district.

3.1 Bhavani River

Bhavani rises in the Western Ghats of Silent Valley National Park in Palakkad District of Kerala. It receives the Siruvani River which has the second tastiest water in the world, a perennial stream of Coimbatore District, and gets reinforced by the Kundah river before entering Erode District in Sathyamangalam. Bhavani is more or less a perennial river fed mostly by the southwest monsoon. The northeast monsoon also supplements its water resources. This river runs for over hundred miles through Erode District, traversing Bhavani and Gobichettipalayam taluks. It feeds the Bhavanisagar reservoir, which takes an easterly course after Sathyamangalam taluk. Near Gobichettipalayam lies the Kodiveri Dam, a mini dam constructed for agricultural

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purposes. It ultimately joins Kaveri in the island of Bhavani, Tamil Nadu, near Erode, with a holistic tributary river of Amutha Nathi, hence called Tiriveni Sangamam. The place where Bhavani joins with Kaveri River is famous for Sri Sangameshwara Temple of Lord Shiva, where according to the Hindu customs people perform the last rights for deceased near and dears.

3.2 Cauvery River

Kaveri rises in the Western Ghats of Kodagu (Coorg) District, in Karnataka, and is joined by many small tributaries. It runs eastward through Karnataka, and at Hogenakal fall takes a sharp turn, east to south. Before reaching this point, it is joined by its main tributary, the Kabini River. From here it runs towards the southeast, forming the boundary between Bhavani Taluk of Erode District and Tiruchengode Taluk of the neighbouring Namakkal District. The Bhavani River joins the Kaveri at the town of Bhavani. The climate is mostly dry and characterized by good rainfall. Unlike nearby Coimbatore district, Erode District has dry weather throughout the year except during the monsoons. The Palghat Gap in Western Ghats, which has a moderating effect on the climate of Coimbatore district, does not help in bringing down the dry climate in this area. The cool moist wind that gushes out of the west coast through Palghat gap loses its coolness and becomes dry by the time it crosses Coimbatore district and reaches Erode. Generally the first two months of the year are pleasant, but in March the temperature begins to rise, which persists till the end of May. The highest temperatures are normally recorded during May. The scanty showers during this period do not provide much relief from the oppressive heat. However, there is an improvement in the climate during the June–August period. During the pre-monsoon period, the temperature reverses its trend. By September the sky gets heavily overcast, although the rains pour down.

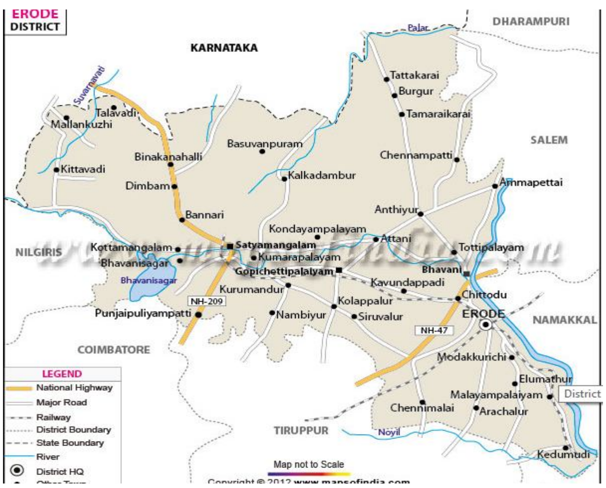

Fig 3 Erode District Map

3.3 Irrigation And Drainage Management In The Erode

Water is provided to the WUAs by a network of irrigation canals. As canals are dug-in, the water needs to be pumped up into the main distributor canals of the WUA. However, depending on the topography, some farms receive the water directly from the dug-in canals. For example, about 66 % of the total water supply into the ERODE WUA originates from the 10 lift irrigation schemes (pumps), whereas the remaining 34 % has surface water supply through gravity canals. The total length of the irrigation canals in ERODE is around 156 km, and the density of the irrigation network is 83 m ha^{-1}. An open horizontal drainage network is used to remove excess surface and groundwater from the area along with the salts, the latter especially stemming from leaching events prior to the vegetation season. The drainage network consists of laterals and collectors. The total length of the drainage system in the WUA is 101 km (drainage network density: 54 m ha^{-1}). Soils in the WUA are predominantly loamy to sandy loam according to USDA classification. The GW level in the study area is shallow and ranges from 1.0–1.2 m below surface during leaching and irrigation events (Ibrakhimov et al., 2007). For monitoring the GW levels and salinity, the national authorities have installed 15 GW wells in the WUA. The socalled “Hydromelioration Expedition (OGME)” of the district is responsible for collecting the GW data of which copies are provided to the WUA office and Irrigation System Authority (TEZIM).

3.4 Establishment Of Rating Curves

As described above, rating curves are based on simultaneous measurements of water level and discharge covering the full range of discharge variation. The velocity-area method, which is the most practical method for measuring stream discharge, was applied in this study. Here, discharge is equal to the product of the cross-sectional area and the velocity. The cross sections were measured at all flow measuring stations from an assumed benchmark (a point of known elevation) before and after the vegetation season to determine the amount of sedimentation, which can disturb the relationship between the head values and the discharge. The width of the canals at the stations was divided into a number of subsections, each containing no more than 5% of the total discharge. For each subsection, canal depth and average velocity were measured. The current meter was placed at a depth where average velocity was expected to occur. Water depths lower than 1 m were multiplied by 0.6 times the total depth of the canal, and the current meter was placed at this depth to measure the average velocity. When depths were larger, the current meter was placed at a distance of 0.2 and 0.8 times the total depth of the canal (Buchanan and Somers, 1969).

The product of velocity, depth and width of the section is the discharge through the respective subsection. The sum of the discharge amounts in the subsections equals the total discharge of the canal. As the main objective of the rating curve is to calculate the discharge for the stages that are not captured by a current meter, the equation for the best-fit-line was used for further discharge calculations Table 1 shows Water balance components for CAUVERY water users association vegetation season

Table 1 Water Balance Components For Cauvery Water Users Association Vegetation Season

Month	Actual inflow (mm)	Intended inflow (mm)	Total outflow (mm)	Actual ET (mm)	Potential Precipitation (mm)	ET (mm)
April	94	84	101	35	85	41
May	246	148	154	118	138	4
June	245	242	115	191	175	9
July	451	308	247	104	164	1
August	456	255	219	124	140	0
September	97	110	45	89	102	0
Seasonal	1589	1147	881	661	804	55

4.4.1 INTENDED FLOW OF WATER (VI)

Intended flow of water or the amount of water supposed to be delivered to the irrigation system from the main canals for the 2007 vegetation season was determined from the dataset of the CAUVERY WUA.

5. MAJOR IRRIGATION SYSTEMS BOTH SURFACE WATER AND GROUNDWATER

Generally, conjunctive use, especially in the spontaneous bform, has developed on the major alluvial plains and their associated aquifers of the world (as discussed above). Foster *et al* (2010) contend that the abovementioned settings, together with variations of average rainfall and geomorphological position, control the potential for conjunctive use for irrigated agriculture. A further driver appears to be water availability, or more pertinently, water scarcity – the pressure to find and utilise other water sources increases as water becomes scarce. Nevertheless, the scale of the adoption of conjunctive use is generally controlled by the scale of the groundwater system. Historically, surface water has been the primary source in the majority of such systems, with groundwater providing an alternative source when surface water availability is low, particularly during periods of drought. However with increasing demand for water, the value of groundwater is achieving greater recognition, becoming in many areas an important primary source of water supply for irrigation. The increased value for groundwater more generally has been driven by growth in irrigated areas that were traditionally supplied from surface water, and hence increasing the demand from these historic sources. The use of groundwater for irrigation has generally increased worldwide (in some cases exponentially) since the 1950s. For instance, surface water withdrawals accounted for 77 percent of all irrigation in the UK in 1950; but with increasing groundwater development, declined to just 59 percent by 2005 (USGS, 2011).

Table 2 Summary of drivers for sole use of groundwater or surface water resources

Drivers of Resource Use	Groundwater Resource	Surface Water Resource
Variable climate	A highly variable climate will typically favour users of groundwater resources, as groundwater characteristically provides a higher reliability of supply than surface water.	
Poor surface water quality	Poor surface water quality (often generated by the irrigation system itself) will favour groundwater use.	
Poor groundwater quality		Surface water will remain the dominant resource when groundwater quality is poor.
Lack of adequate infrastructure	Gaps or failures in infrastructure (or in its operation and maintenance) that delivers surface water to users will favour groundwater use.	
Depth of groundwater resource		Groundwater resources found at significant depths below the surface will incur significant pumping costs and hence often favour the use of surface water resources.

In surface water irrigation commands, there can be differences in water security based on how close the particular farm off-take is to the primary diversion canal, especially where the delivery infrastructure is operated (or performs) in an inefficient manner. Those close to the primary source (termed the Head of the irrigation command) are likely to benefit from regular supplies whereas those at the end of the delivery system (the Tail) are subject to the efficiency of the delivery canals and the compliance of other farmers to access rules. In some cases the quality of the delivered water will deteriorate as the delivery system also sources Groundwater discharge from irrigation induced shallow water tables. In such cases, individual wells become an insurance policy against both diminished and uncertain supply and poor water quality.Table.2 shows Summary of drivers for sole use of groundwater or surface water resources.

5.1 About Governance

This paper is essentially about the governance approaches that are required to implement conjunctive use management in irrigation commands. Groundwater governance is defined here as the process by which groundwater resources are managed through the application of responsibility, participation, information availability, transparency, custom and rule of law. It is the art of coordinating administrative actions and decision making between and among different jurisdictional levels – one of which may be global (adapted from Meganck and Saunier, 2007). There are different implications for governance arrangements depending whether one is retro-fitting planned conjunctive use to an existing irrigation command, or whether it is being developed in a *greenfields* situation.

In both cases, the following will be required:

- institutional strengthening to ensure that integrated water management occurs, together with explicit decisions about system management and operation. Institutionally, international experience is that surface water management is almost always separated from groundwater management, though they may share the same 'head' institution or governing authority. It is the authors' view that major institutional reform is required to bridge this 'divide' not just in name but through planning behaviours and operational arrangements;
- commitment to sustainability objectives (that target environmental, social and economic outcomes);
- decisions about future investment in infrastructure and cost recovery;
- strong policy and legislative leadership to drive a planned approach, within a compliance culture;
- clear and robust implementation/delivery mechanisms to ensure the central planning/policyapproach can be taken through to on-ground action;
- participatory involvement by the grass-roots water users and related stakeholders; and
- technical knowledge of the surface water and groundwater systems to enable efficient use of both resources, and capacity building to apply this technical knowledge.
- However, irrigation commands where spontaneous conjunctive use has evolved over time will also require a significant investment in planning to enable integration of opportunistic pumping within the optimal conjunctive use framework. This will require (in addition to the above):
- establishment of institutions that provide complementary planning and regulatory functions;
- modification of current behaviour, that may be achieved through;
- implementation of a compliance management framework
- potential use of either market instruments or direct incentives to encourage/effect farmer change; and
- argeted extension programs that through education and demonstrations enable farmers to realise the on-farm benefits to be provided by the planned approach.

Because spontaneous conjunctive use has usually evolved over time, policy objectives such as sustainability may not be fully evident or understood, unless serious resource depletion is already placing physical constraints on access. Regulated reductions in access may therefore create tensions, highlighting the value in improved understanding by irrigators, and the value in stakeholder involvement within the planning process. Where conjunctive use has grown up spontaneously around a previously surface water dominated irrigation command, one might expect management to be somewhat centralised and rigid. Where it has grown around a strongly groundwater dominant irrigation command, management approaches may be less rigid and more informal, to the point where there is little regulatory control. Each of these end members will represent particular challenges in achieving a governance model that is able to support a technically robust and appropriately managed conjunctive management model.

6.CALCULATION OF PERFORMANCE INDICATORS

To assess the operational performance of the irrigation scheme, first the targets of the performance assessment need to be formulated (Bos et al., 2005). Then the appropriate performance indicators need to be selected from comprehensive lists provided, e.g., in the ICID guidelines (ICID, 1978). The rationale for selecting these indicators includes the feasibility of taking measurements, the accuracy of measurements and the cost effectiveness (Bandara, 2003). In this study, the performance assessments mainly targeted water availability and water use efficiency at both systems and field scale. Furthermore, water distribution was investigated at different levels in the canal system. Therefore, delivery performance ratio (DPR), relative evapotranspiration (RET), depleted fraction (DF), drainage ratio (DR), overall consumed ratio (OCR), field application ratio (FAR) and conveyance ratio (CR) were selected as performance indicators. These indicators are based on the components of the water balance (see section 3.2.2). The following subsections define the indicators and then describe the methodology for determining the parameters used in these indicators.

6.1 Delivery Performance Ratio (Dpr)

The delivery performance ratio (DPR) is an indicator used to assess the reliability of the water distribution in the irrigation scheme. Bos et al. (1991); Clemmens and Bos (1990) and Molden and Gates (1990) rated it as the most important indicator for the operational performance of the water distribution in the irrigation scheme.

6.2 Drainage Ratio (Dr)

The degree to which the supplied water is consumed in an irrigation scheme is defined as drainage ratio (DR) and is also useful for diagnostic purposes.During long-term observations of a catchment, DR and DF should sum up to 1 (Bos et al., 2005). In irrigation systems with shallow

GW tables, this value can be used as an orientation to assess the variations of the GW level and therefore the risk of soil salinization.

6.3 Overall Consumed Ratio (OCR)

The overall (or project) consumed ratio (OCR) quantifies the degree to which the crop irrigation requirements are met by irrigation water in the irrigated area (Bos and Nugteren, 1974). The ratio allows, among others, evaluations of the overall system efficiency. Field application ratio (FAR)

The field application ratio (FAR) is the measure of water losses in the field. This efficiency indicator is defined as (ICID, 1978)

7. HYDROLOGICAL TOOL FOR IRRIGATION MANAGEMENT

During the past few decades, competition for water among different users has increased manifold in many parts of the world. The development of new resources is not economically and environmentally viable. Therefore, the increasing demands for water can only be met by using the existing resources more efficiently (FAO, 2003). The majority of irrigation networks around the world are operating at a low overall efficiency of 30 % against the minimum achievable efficiency of 56 % (Sarma and Rao, 1997). Inappropriate system design causes in a low overall efficiency, but even with appropriate design, a proper management for the effective operation and maintenance of irrigation water delivery systems is essential, and worldwide evidence shows that significant improvements can be gained through irrigation scheduling (Malano et al., 1999). Although the crop yield and seasonal evapotranspiration (ET) relationship have been widely used for the management of water resources, the effects of timing of water application are also of key importance especially for irrigation scheduling with high temporal resolution (Hanks, 1983; Vaux et al., 1983; Howell, 1990). Irrigation scheduling should answer as to when and how much to irrigate a cropped field. Given the complexity, a number of computerized simulation models (Kincaid and Heermann, 1974; Smith, 1992 and Mateos et al., 2002) to support and improve irrigation scheduling are available.

7.1 Irrigation Scheduling Model

The FAO procedure, as described by Doorenbos and Pruitt (1977) and Allen et al. (1998), and implemented in the CROPWAT software (Smith, 1992; Clarke et al., 1998) was selected for this study to develop the irrigation schedule (IS) for the cotton crop, which is grown on more than 50 % of the irrigated area of the WUA (see Chapter 4). As the CROPWAT software has no facility to compute the capillary rise, which is an important parameter in water balancing under shallow GW conditions, the model was adapted to the local conditions (shallow GW levels). The capillary rise computed outside the domain of the model with the HYDRUS-1D model was introduced in the CROPWAT model by using the so called 'users defined irrigation' option.

7.2 Scenarios Used In The Model

A main reason for using models results from their ability to simulate alternative irrigation scenarios based on different levels of allowed crop water stress and on various constraints in water availability (Pereira et al., 2007). In this study, various scenarios were developed to compute optimal irrigation schedules for cotton improved irrigation

7.2.1 Optimal Irrigation Scheduling

For four irrigation efficiency scenarios (see, Chapter 3), S-A; current irrigation efficiency or business-as-usual (BAU), S-B; improved conveyance efficiency, S-C; increased application efficiency and S-D; improved conveyance and application efficiency, under characteristics of six developed hydrological response units,S-SL (shallow-silt loam), D-SCL (deep-silt clay loam) and M-SL (mediumsilt loam), GW levels were simulated using the FEFLOW-3D model. The 12 simulated GW levels for the combination described above were then introduced in the HYDRUS-1D model to compute the capillary rise contribution for cotton against each GW level. For details on the methodology see Chapter. The computed capillary rise was then introduced in the CROPWAT model to develop 12 optimal irrigation schedules for cotton.

7.2.2 Optimizing Irrigation Scheduling With Reduced Water Supply

For the years of low water availability, optimized irrigation schedules under deficit irrigation situations were developed. In this scenario, the water was reduced by 25 and 50 % of the current water supply. The situation can be managed in two ways, i.e., a proportional deduction of water from each irrigation event as suggested in the optimal irrigation schedule, and b) a reduction in the number of irrigation events. The impacts of reduced water supply for these two managerial options was compared for the proportional yield losses simulated in the CROPWAT model using the yield reduction functions proposed by Doorenbos and Kassam.

7.3.Irrigation Scheduling

7.3.1 Optimal Irrigation Schedule And Practiced Irrigation Schedule

The optimal irrigation schedules for the improved irrigation efficiency scenarios for cotton under scenarios S-A, S-B, S-C and S-D, show that the capillary rise contribution has a significant impact on the irrigation schedule. In all scenarios, the irrigation quota for the HRUs increases in the order S-SL < M-SL < DSCL.The quota is related to depth of GW levels; they are shallowest in the S-SL and deepest in the D-SCL HRUs. In the S-SL HRUs, the lower irrigation quota is due to a higher capillary rise contribution due to shallow GW. In contrast, the higher irrigation quota in D-SCL is due to a lower capillary rise contribution also due to shallow GW levels. The comparison of the irrigation quota for different irrigation efficiency scenarios shows that the irrigation quota does not differ much in S-A and S-B for all HRUs. The small difference in irrigation quota for S-A and S-B is due to the small difference in the capillary rise contribution for these scenarios. However, the irrigation quota for S-C and S-D differs substantially from that of SA and S-B. The higher irrigation quota for S-C and S-D compared to S-A and S-B is again due to the difference in capillary rise contribution. The low values in S-C and S-D increased the irrigation quota in these scenarios. The trend of change in irrigation quota for these scenarios among HRUs is the same.

Intensified maintenance of canals would lead to higher conveyance efficiency. However, lining is not recommended due to the shallow GW, as lining requires plentiful resources and to maintain the lining with fluctuating GW levels needs additional resources. An increase in irrigation network efficiency can also be realized by reducing operational losses. Better coordination of operational activities would avoid or at least reduce the overflow of water from the canals into the drains. Therefore, the impact of efficiency improvement on the current irrigation and drainage system assessed in this study clearly shows that compensation for the safety net function of the groundwater needs to be considered by institutional strengthening to make water supply at the farm level more reliable.

8. CONCLUSION

For assessing the operational performance of the WUA, the water balance components actual inflow, intended inflow, total outflow, actual and potential evapotranspiration .Flow of water is a product of the cross-sectional area of the canal and the velocity with which water is passing through this cross-section .The uniform cross section of the CAUVERY canal at Pump-1 and Pump-2 is due to the fact that flow measuring stations were established where water management authorities had constructed the concrete trapezoidal infrastructure to facilitate the discharge measurements. The irregular shape of the BHAVANISAGAR canal is due to the earthen cross section at this flow measuring station.

In these guidelines, water requirements of major crops such as cotton have been elaborated for different agro-hydrological, climatic and ecological areas whilst considering among others the contribution of shallow groundwater (GW) to soil moisture enhancement and soil texture. These guidelines allow a quick, but only rough estimation of large-scale water needs at district and regional level and are still being applied. In the Soviet past, with its emphasis on agricultural production at all costs, water availability, shallow GW tables and drainage problems were less pressing issues, even in remote regions. Despite the lack of precision in the calculation of water needs, water resources used to be sufficient to satisfy requirements under less stringent resource management.

- 33 % of the surface water can be saved by improving the irrigation efficiency near to the target values but this would result in a decline in the GW level, which is not a feasible option for the farmers in the region.
- Shallow GW levels provide 19 % of the crop water requirement for the whole WUA, and farmers want to use GW levels as a safety net to cope with the unreliable water supplies.
- An option to improve the irrigation efficiency along with maintaining the current GW levels is to institutionalize the control of drainage outflows, which at the moment is practiced by the farmers on an individual basis.

The CROPWAT model uses capillary rise values to calculate the water balance and optimal IS for the cotton crop and to develop water management scenarios under a deficitary water supply. In the deficitary water supply scenario, optimal IS of cotton with minimum yield loss was developed for a 25 to 50 % reduced surface water supply, either by proportional deduction of the irrigation quota or by reducing the number of irrigation events. First of all, recharge rates vary substantially within an irrigation scheme due todifferences in vegetation, soil texture, GW levels and other factors (Fazal et al., 2005).Consequently, the common procedure to measure GW levels by observation wells that mirror the GW conditions mainly in the close vicinity of the wells is inadequate. Secondly, the WTF method is designed for estimating, overall seasonal recharges but not for managing situations with high recharge dynamics within theseason as occur in the study region. Thirdly, in case of the rate of recharge being equal to the rate of drainage from the GW, according to the WTF method no recharge would be predicted and this also is not conform to the reality of the situation in the study region.

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