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Relevance of minor irrigation and its restoration to sustain agriculture in Andhra Pradesh – An Overview

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ABSTRACT
Sustainable irrigation, keeping in view all the socio-economic constraints, is vital for overall economic progress of our country. Andhra Pradesh socio-economic structure is linked to agriculture reliant economy. For sustenance of food production, it is essential to strengthen the irrigation potential. It is accepted by both the government , experts and the NGOs that due weightage should be given to minor irrigation as 65% of agriculture is dependent on minor irrigation. For well-being of different types of aquifers (shallow/deeper; soft/hard rock), steps need to be taken to revitalize failed and defunct bore wells through Managed Aquifer Recharge (MAR) technique. An overview of merits and demerits of existing minor irrigation schemes, especially groundwater schemes, and needed steps to ensure better utilization of water resources through Participatory Hydrological Monitoring is presented. A broad exposition of Plan Document released by A.P. State Govt is included, to emphasize the fact that the Govt is well aware of the importance of minor irrigation, but implementation is hampered due to various constraints. From the Plan document it is clear that immediate steps are to be taken to revoke the use of dilapidated tanks/ ponds and put into better use ground water resources by rehabilitating defunct bore-wells and adding new, giving due importance to aquifer management through farmer participatory mechanism.. Importance of conjunctive utilization of surface and sub-surface waters is discussed. Apt steps to identify problems and solving them are detailed. Need for support to field earth scientists and better interaction between lab & theoretical experts and field scientists is stressed, as inputs from all categories of scientists and technical experts are vital for ensuring sustenance of aquifer health.

INTRODUCTION

For management of any scheme, especially that which has direct impact on rural development like the various water supply works, one should have sound planning for execution and maintenance. Before envisaging any project, the planners should treat water as any other of the earth's resources, however, taking into consideration the impact of global warming/climate change on its quality and quantity in time and space. It must be used intelligently and a balance should be struck between immediate need and also those of future generations. The most pressing environmental problems are associated with resources that are re-generative but are under-valued and are, therefore, in danger of exhaustion. Water, even though, a renewable source has a finite capacity to assimilate pollution. To correct it, decision makers need better information about environmental processes that affect both quantity and quality of surface and ground waters. Environmental policy can reinforce its efficiency in resource use and provide incentives for adopting less damaging technology and policies. As such in planning any type of water works (either for irrigation or drinking), one should introduce and coordinate various implicit technical and administrative parameters for properly locating the source, tapping, transporting and distributing the same in a systematic way for the benefit of millions of human beings, while ensuring sustainability of the schemes. Wasteful expenditure on technically unsound schemes that may not see the day even in a couple of decades must be avoided. Experimentation can be encouraged, if it is backed by sound logic. In order to solve the water related problems, a long term planning and management strategy is to be evolved and implemented. This will, inter-alia, require a large pool of persons with requisite training and background in hydrology, and watershed management. Productivity, in general, is a ratio referring to the unit of output per unit of input. The term 'water productivity' is defined as the physical mass of production or the economic value of production against gross inflows, net inflow, depleted water, process depleted water, or avoidable water. Efficiency is generally associated with a transformation of an input into an output. Both engineering and agronomic concepts have constituted to water-use efficiency. The engineering focus defines the concept of irrigation efficiency as the amount of water from the main water source that can be effectively supplied to the root zone. The agronomic focus, however, illustrates the concept of crop water- use efficiency, defined as the fraction of water stored in the root zone that is transpired by the crop. This concept includes both crop water- use efficiency and crop water productivity. The combined agronomic and engineering focuses result in water-use efficiency, defined as the ratio of transpiration (mm) to total water supply (mm), and water productivity, defined as the ratio of yield (kg) to total water supply (mm) (Vishnu Vardhan et al., 2010). Due to ignorance of these basic facts, irrigation waters are supplied and used in a blind manner, leading to present day water scarcity scenario.

As water availability is becoming difficult in space and time, for success of any irrigation scheme, people's participation in watershed planning, implementation, monitoring, execution and management is as vital as the scientific input in deciding the technology intervention. People's participation in planning, development, and maintenance is vital to achieve sustainability in the watershed development programme. This aspect needs to be given due importance, at par with scientific input in deciding the technology intervention. Insufficient participation leads to inadequate watershed management of an agricultural land, and to environmental degradation, while sufficient participation yields benefits in the form of reduced erosion and increased productivity (Palakshappa et al., 2010). The objective of participation is to listen to their voice, and to give them a chance to exercise their voice and choice and hence, develop the organizational and managerial skills to find solution to the problems when they arrive. This aspect is being given due weightage since a decade, both by the Govt and NGOs. Success is noticed, where this is practically in use.

In Andhra Pradesh, where different types of environments and geological situations are present a systematic planning is essential to utilize surface as well as sub-surface waters, available in different zones (geological and geographical). Since water is needed both for drinking and irrigation purposes, one should first identify a specific problem associated with a project and then take steps to solve the same to avoid unnecessary wastage of resources and funds. It is, thus, necessary to give equal importance to minor irrigation schemes along with the medium and major ones. If the scheme is for supplying potable water for usage of urban or rural conglomeration, one should take certain necessary steps that are different from irrigation schemes, for providing water that is free of pollutants like (a) biological, (b) mineralogical, (c) chemical, and (d) natural. In this case, one should first locate a source, then purify the source and subsequently transport the available waters keeping in view all the socio-economic constraints in such an operation. As this problem is slightly different from irrigation, one may have to introduce critical filtering of waters to avoid health hazards that vary from region to region depending on various natural and man-made parameters. Similarly, in the case of irrigation purposes it becomes important to find sources that are devoid of chemical pollutants that may damage the crop. So, for both irrigation and drinking water programmes, one has to identify an individual problem and take steps to resolve the problems by producing apt results that can have direct and immediate impact, without adversely affecting long range targets.

I am presenting here a general over-view of policy issues which are relevant to groundwater exploitation in Andhra Pradesh, with emphasis on the importance of the economic, technical and social issues, which arise in the use of groundwater for irrigation and also those involved in the conjunctive use of ground and surface waters. The aim is to direct attention to crucial areas and to produce hypotheses which will be subsequently tested and verified by individual experts so as to enable guidelines to be prepared for use in the evaluation of future projects. Importance is given to policy suggestions stressing the advantages of organized groundwater exploitation compared to major irrigation facilities. Some specific geological and technical aspects of groundwater dynamics (including exploration and exploitation) are included. A sub-section on Lift Irrigation Schemes (LIS) is added to bring in to focus conjunctive use of surface and ground waters. I do know the presentation covers only some aspects. As an Earth Scientist and as one who had an exposure to various administrative structures, I am aware of the number of hurdles in implementing the suggestions. As such the suggestions and observations made in the text are not aimed at finding faults in the existing system. I only want the concerned, including scientists and technical experts, to lend an ear to the fervent appeals made by the farmers. Due to my own limited exposure to various developments, I have mainly concentrated on groundwater dependent irrigation, while exposing the reader to broader aspects of tank irrigation and Lift Irrigation. For success of Minor Irrigation sector, all the three components need to be given due weightage. Even though some may question the rationality in exposing Earth Scientists, to socio-economic aspects of the Minor Irrigation I have decided to build up the article to comprehensively bring in to focus the problems in strengthening the Minor Irrigation sector, as Earth Scientists can play a significant role in reviving the sinking irrigation potential.

MINOR IRRIGATION – SUSTAINABILITY

Initiatives of the State Government and Existing Reality

Minor Irrigation holds the key for an equitable, quick, and effective expansion in the agriculture sector leading to a sustainable growth in the rural economy. Centrality of Minor Irrigation in rural economy was highlighted in no uncertain terms by the high level committee constituted by the Government of Andhra Pradesh (during 2003-2005) to study the implications and factors responsible for the phenomenon of escalating farmer's suicides. The **Jayathi Ghosh committee** looking into the conditions responsible for creating an adverse atmosphere for the farmer picked up the declining tank irrigation systems for special mention as one of the factors precipitating farmer's insecurities. Development and maintenance of water bodies has been a historical legacy that Southern India inherited since ancient times. The southern part of India, under the Chola, Pandya, Pallava, Chera, Vakataka, Kakatiya, etc., dynasties, developed vast networks of tanks and canals, famed the world over, to irrigate crops and enhance agrarian production. The oldest and indigenous water-harvesting financially performing structures sustained by institutions, customs and practices built around them served and benefited, varied sections for centuries. The usage norms, access to water, water distribution between varied users, maintenance designs, options and costs became the concern of village / local community. Under the Colonial and Zamindari system as maintenance of water bodies got linked with the state and its apparatus the maintenance of the systems were negatively affected resulting in the poor efficiency of the systems and inequity in the access and sharing of the resource. The availability of cheap electricity and shift towards well irrigation further shrank the area under tank irrigation all over the country, including A.P, since the 60's. The state has the largest number of tanks – amounting to almost 80,000 tanks and the largest area –estimates put the figure at almost 1.8 million hectors (considerable number even in the semi arid tracts and drought prone areas). Heavy silting of tank beds, choking up of feeder channels, leaking and weak bunds, leaky sluices and dilapidated surplus weirs and ill maintained distribution channels, encroachments in the tank bund- foreshore- water spread and supply channels, deforestation and denudation in the catchments areas, housing and urbanization and indiscriminate use of tank beds as dumping yards led to a steady deterioration and dilapidation of the tank conditions. The decline and disuse of tank systems had a debilitating impact on the drought prone regions as many of the tank-fed areas are situated in the districts where there are no possibilities of providing other methods of irrigation.

If all the range of minor irrigation such as tanks, lift irrigation systems and ground water based irrigation are included, the minor irrigation contributes almost 67% of the irrigation in the state. In the total potential created by utilizing available water resources through major, medium, and minor irrigation sources which is about 3.6 million hectares, the minor irrigation component of 1.792 compares well with the potential created by the major and medium irrigation (1.560 and .264 million ha….as per statistics released by the state govt during 2010). This represents the figure of the area irrigated by tanks which both in absolute and relative terms been halved from about 1 million hectares in 1990 (24% of irrigated area at the time) to about 0.5 million hectares in 2004 (12% o f irrigated area). It is a fact that the percentage of area dependent on tanks for irrigation since the time the state started its targeted focus on strengthening Major Irrigation systems in the early post independence period has reduced to less than half in 45 years between 1955 and 2000 (from 38.88% in 1955 to 16.06% in 2000). While this decline is a cause for concern it also underlined the vast potential that the revival, renovation and stabilization of the tank irrigation system can have on increasing the irrigation potential in the state. With the investment and benefits ratio on Major Irrigation schemes becoming prohibitive the focus of policy makers came back on minor tanks to provide fillip to rural economy with a realistic and effective strategy of irrigation development. The *Jayathi Ghosh Committee* constituted to study the agricultural crises and increasing farmer's suicides in the state in 2003 categorically highlighted the lack of policy focus on the marginalized sections in rural areas. The committee traced the crisis in agriculture in the state to the public policy deficiency which reduced the protection accorded to farmers by exposing them to the volatility of markets, reduced critical public expenditure that destroyed institutional protection and the failure to generate alternative non-agricultural economic activities. The uneven distribution of canal irrigation and the decline of surface water sources especially tanks were found to be responsible for the escalating expenditure of the poor farmer for accessing water in drought prone conditions. Inadequate rainfall because of the series of continuous droughts, silting up of tanks, over-exploitation of groundwater, falling ground water levels, increased costs of bore wells and the search for depleting ground water collectively enhanced cultivator's indebtedness and hence his economic vulnerability. *The recommendation made by the Ghosh report that* "top priority must be given to the cleaning, repairing, maintenance and development of tanks and ponds. This must be done in a mission mode on an urgent basis, possibly using labour resources that will be made available under the Employment Guarantee Scheme of the central government. The plan must be to restore existing tanks and develop new tanks without jeopardizing supplies to the old tanks. Further, feeder channels to many tanks have been cut or destroyed; these must be restored. Wherever possible, water from large irrigation schemes should be made available for feeding existing tanks. There should be an inventory of traditional water bodies which must be continuously updated" set the stage for a reorienting of the policy focus of the state irrigation policy towards addressing the concerns, issues and prospects in the Minor Irrigation systems. The direction of the policy spotlight on Minor Irrigation identified to address the agrarian crisis threw up a host of issues and possibilities opening a new stage in irrigation development in the state. To enhance the area of cultivation, on a sustainable basis, it was recommended in 2005 to put into action rehabilitation of dilapidated tanks, construction of new tanks, restoration of defunct bore-wells and construction of new bore-wells (while taking into account the optimum usage of aquifer capacity) using funds from Central govt and loan from National Bank for Agriculture and Rural Development (NABARD).

Addressing service delivery challenges whose 'minor' scope has for long failed to generate political / administrative attention and operating in a domain, long neglected by policy makers was the legacy which the irrigation department had to improvise upon. The focus directed upon Minor Irrigation started a plethora of activities on how to effect positive changes that are financially and physically sustainable in the long run. The deliberations and discussions initiated in this connection zeroed in on an overall objective of reviving the potential of minor irrigation – through building of new tanks and rehabilitation of old tanks; facilitating practicing of integrated water resources management – focused upon addressing the livelihood needs of the tank users. Institutionalization of participation of water user bodies in planning, implementation and monitoring of Minor Irrigation systems, operationalization of project mode, direct involvement of Non-Governmental Organizations, addressing water resources management within an integrated framework are few of the milestones that the Irrigation & Command Area Development(I&CAD) of Minor Irrigation Strategy established in the country.

The working group on the Minor Irrigation Programme for the Formulation of X Five Year Plan (Year 2002-2007) constituted by the Planning Commission G.O.I. underscored the need of developing a participatory minor irrigation system. The Steering Committee of the Planning Commission emphasized on irrigation sector on renovation, improvements of existing minor irrigation tanks and canal systems and the strong endorsement by Jayathi Ghosh of the need for effecting a policy change towards refurbishing the irrigation potential of tank irrigation schemes were key catalysts directing spotlight on minor irrigation. The state commitment to and the ushering of the Participatory Irrigation Management (PIM) in the state through the passing of the Andhra Pradesh Farmer's Management of Irrigation Systems was another factor molding a participatory minor irrigation management approach. The key policy focus of the new minor irrigation approach was on targeting focused integration between new tanks, dilapidated tanks and ground water potential leading to a creation of additional capacity in the next five years. The key areas of focus were:

New Tanks

The first component of the minor irrigation strategy was on creating new irrigation potential through the construction of new tanks especially in arid and drought prone districts like Anantapur and Adilabad where there was little scope for providing alternative irrigation options. Building of new tanks – based on hydrological and financial feasibility studies was targeted to generate an additional irrigation potential of about 10 lakh acres in the state.

Revival and Restoration of Old Tanks

Andhra Pradesh by 2005 had an existing (created) Irrigation Potential of 35 lakh acres. However, operating at a 30% efficiency, the state was actually utilizing just above 10 lakh irrigation potential. The state through Revival and Restoration of old tank structures intended to improve the water use efficiency of these minor irrigation systems to almost 60% resulting in actualization of additional 10 lakh acres irrigation capacity. The water management component, that focused on incorporating community participation in all stages of tank sustainability focused upon strengthening tank based livelihoods through a multi-disciplinary approach has laid down the details of a pioneering method of decentralized and livelihood focused tank management system. In fact the methodology that the I&CAD drafted for facilitating a community managed tank revival and restoration process has been incorporated within the guiding framework for the conduct of the "National Projects on Repair, Renovation and Restoration of Water Bodies Directly Linked to Agriculture".

Groundwater Management

The third key focus in the minor irrigation strategy was on facilitating conjunctive use of surface and ground water through addressing ground water management concerns. The action plan focused on generating of additional potential of 10 lakh acres through new bore wells and dug wells in the period 2004-14. The thrust was on creating additional capacity in tribal areas in Northern Andhra Pradesh that have traditionally fallen outside conventional irrigation system.

Delineation of designated circles for Minor irrigation works and creation of a multidisciplinary focus for ushering of PIM in tank management were two significant interventions made for smooth implementation of minor irrigation management. Conventionally, minor irrigation works, because of perceived smallness were often clubbed with Major and Medium irrigation works and undertaken by common circles in all the projects. In order to ensure that minor works are not overlooked in favour of Major / Medium works, the department proposed a separate jurisdiction for minor works by designating selected circles exclusively for the same. 11 minor irrigation circles and one quality control circle working under the Minor Irrigation Chief Engineer were proposed to conduct both the construction and water management works of minor irrigation exclusively. (Courtesy: Andhra Pradesh Water Reforms-2010).

Unfortunately, even though everyone is aware of the importance of Minor Irrigation nothing substantial has been done to implement the recommendations of the Jayathi Ghosh committee and recommendations of the high level committee constituted by the state govt. With focus shifting to mega Major Irrigation projects the three segments of Minor irrigation continue to suffer. Unfortunately, practical action often differs from proclaimed ideals. The credibility of all the above project proposals is much sapped by the day to day compromises of political life, by adverse socio-economic conditions and by the short comings of scientific knowledge, not least an interdisciplinary understanding of the relationships between natural ecosystems, socio-economic processes and cultural belief systems. We need to keep in view that the water ethic contains that philosophical shift from the strictly utilitarian divide-and-conquer to an integrated, holistic approach, which views people and water as related parts of a greater whole. As such every segment of our society should contribute to the success of the Minor Irrigation, instead of blaming one or the other.

Having exposed the reader to the planned strategy of the state government, I outline below some specifics.

REHABILITATION OF MINOR IRRIGATION TANKS - SOME SALIENT INPUTS

A tank is a low earthen bund thrown across the shallow valley to hold the rainfall runoff from the catchment area above. Tanks may be either isolated or in cascades. In a cascade, when the upper tank is full, the spill over the surplus weir is led into the tanks lower down one below the other as a cascade until the last tank spills into a drain or river. Increasing crop per drop is the major aim of tank rehabilitation (Anuradha et al., 2010). Harvesting the optimal runoff volume available during the monsoons, for ensuring natural flow into surface water bodies (tanks, ponds), and artificial recharge to augment the ground water resources for achieving water scarcity is a viable methodology. This augmentation methodology needs to be up-scaled with scientific approaches and strategies. Understanding and standardization of catchment characteristics of watershed in hard rock areas becomes essential for implementing watershed development programmes, which include proper management of tank irrigation. Localised and traditional surface water management over hard rock areas, though effectively practiced through tank systems, however, due to lack of maintenance, encroachment of catchments and modifications to the tank irrigation system resulted in failure of tank irrigation. As stated by the Jayathi Ghosh committee, it is essential to revive tank irrigation to sustain agriculture in A.P. The deterioration of tank irrigation over years is a common function of tank system. As correctly pointed out in the Plan Document (salient features described earlier) the deterioration started with shifting of irrigation practices, from around 1960s. It is important to examine the main factors that have contributed to the order of deterioration. One of the important factors that have arisen out of the analysis is the silting of the tank and considerable reduction of inflow into the tank. Complete desilting of old irrigation tanks may not be an economically viable proposition, to rejuvenate the efficiency of the tanks, as these structures are of larger dimension. Infiltration studies conducted by Muralidharan et al (2005) indicated that the percolation efficiency of tanks could be revived by optimum desilting process, which is economically viable. The study indicated that in semi-arid regions of Andhra Pradesh removal of 30-40 cm silt has achieved an improvement of infiltration from 10-16 mm/hr to 300 mm/hr. The other important factor that has contributed to the negligence of the tank system is the poor inflow to the tank and inadequacy of supply to the command area. Due to this phenomenon, the tanks are functioning as evaporation pans. Owing to the influence of human activities in catchment part of the tank system, the feeder streams failed to drain the water into the tank to the capacity for which the tank was created. This has resulted in siltation of tank bed, destruction to tank bunds and other ill effects. These non functioning tanks are to be revived to the extent possible to meet the demand for agricultural activities and recharging the groundwater system of the area. Before taking up rehabilitation one has to study the hydrological environ of the minor irrigation tank to demarcate the catchment area of the tank in the form of a watershed area. Tank rehabilitation can be effective only when the entire system,viz, tank boundaries, tank catchment zone and tank ayacut are set right, using area specific designs. Effective management of tank system requires the ability to predict dynamics of subsurface flow .This can be achieved by building appropriate “Flow Models”, using both deterministic and stochastic modelling techniques. Since down-stream wells and bore-wells depend on the subsurface inflows from the tank system, to optimally fix up usage of available water one has to come out with a conceptual transport model, to fix up boundaries for use of the tank waters. Such a fixation can enhance the longevity of a tank system and the tank reliant agricultural practices.

RELEVANCE AND ROLE OF GROUNDWATER IN IRRIGATION

As society demands larger and larger quantities of fresh, better quality waters, the utilization of groundwater, has become vitally important to the society since the availability of surface water is not guaranteed in each and every part of the State. Hence, groundwater resources, which are also much less contaminated compared to surface waters, should be tapped systematically to augment the available surface supplies Since many who are associated with groundwater usage are not conversant with oft used technical terminology some details are given below to make the presentation useful to both technical and non technical personnel.

Groundwater -- Basics

A geological formation which can yield water in sufficient quantity to be of consequence as a source of supply is termed as **aquifer.** Such formations are porous and pores are interconnected. The saturated rock formations in the nature form the aquifer under different conditions. For example, deposition of weathered material forms an aquifer. Various types of aquifers are formed under various conditions. They are classified as 1) confined aquifer, 2) Unconfined aquifer and 3) Semi- Confined aquifer. The first one provides good quantity of water, if nurtured properly. The occurrence and movement of groundwater in the aquifer are characteristically defined by two parameters, namely, **transmissivity** and **storativity**. The ease with which groundwater flows in the aquifer is defined by **permeability**. It is often expressed as the quantity of water which flows across the unit cross- section of the aquifer under unit hydraulic gradient per unit time. Similarly, the rate of groundwater flow through the cross – section of unit width and whole thickness of the aquifer, under unit hydraulic gradient is defined as transmissivity of the aquifer. It is the product of aquifer thickness and permeability. The volume of water released from or stored into the aquifer is defined by the storage coefficient (storativity) or **specific yield**. It is the amount of water released or stored into the change in the head of aquifer normal to the surface area of the aquifer. The **storage coefficient** is a non- dimensional quantity. The storage coefficient refers to the confined part of the aquifer, whereas the specific yield refers to the unconfined part of the aquifer. Pumping test is conducted to determine the aquifer characteristics. These tests also help in having information about aquifer behavior (Singh, V.S, 2006). Unfortunately, these tests are not carried out and aquifers are put under considerable stress due to blind way of exploitation, leading to damage to the aquifers and in turn to the groundwater usage. The **watershed** or **basin i**s a natural hydro-geomorphological drainage unit having distinct surface water divides as boundaries. It comprises the total catchment area of a particular river or stream that contributes runoff water to the flow cycle. Groundwater recharge evaluation, when carried out in a representative watershed or river basin is useful for estimating safe yield and for better water resources management strategies. Groundwater recharge, i.e., the fraction of water input, which reaches the water table after the precipitation has undergone losses due to interception, runoff, evapotranspiration and soil moisture storage in the soil zone, is an important parameter and its accurate estimate, even though difficult, is essential. The two principle types of natural charge to groundwater are direct/ primary and indirect/ secondary. The direct recharge results from vertical percolation of precipitation through soil and unsaturated zone. The indirect recharge results from percolation through beds of surface water bodies such as tanks/ ponds / lakes, streams, canals, return flow from surface water applied irrigation. The principal replenishment to groundwater resources on a regional scale is by direct recharge. The groundwater resources in unconfined aquifers can be classified as static and dynamic. The static resource can be defined as the amount of groundwater available in the permeable portion of the aquifer below the zone of water level fluctuation. The dynamic sources can be defined as the amount of groundwater available in the zone of water level fluctuation. The replenishable groundwater resource is essentially a dynamic resource, which is replenished annually. Annual recharge or input to the groundwater system in a watershed or basin is thus an important parameter to be measured for a systematic planning of exploitation of groundwater reserves and for determining permissible total draft from existing and recommended wells in the area. The factors affecting natural recharge rates are amount and intensity of rainfall, gap between rainfall events, infiltration capacity of surface soil, evapotranspiration, surface topography, compaction and structure of soil, hydrologic conditions. These conditions impose a limit on minimum amount of rainfall required to effect groundwater recharge. The rate at which water table recharge occurs is also depending on the thickness of the unsaturated zone. Where the unsaturated zone is thin, recharge can reach the water table fast, resulting in a localized groundwater mound. Soil moisture percolating through the unsaturated zone beneath upland area takes longer time to reach the water table. Recharge varies across catchments, because the controlling factors vary both in their nature and size (Rangarajan, R., 2006). In many areas covered by hard rocks are generally drained by the seasonal streams which are generated from the higher grounds and flow along topographical slopes. Most of the geographical area of the hard rocks can be classified into watersheds, mini-basins, sub- basins and basins based on the drainage orders. A basin may consist of several water sheds and each watershed can be identified by the surface water divide. Along these water divides, the aquifer system of a particular watershed may not have interaction with the aquifer system of adjacent watershed, where the structural features like faults, fractures, dykes etc may interlink the aquifer systems. Therefore, the boundaries can be assumed along the surface water divide with no flow conditions. In cases where the surface as well as hydro-geological evidences is known for inter - watershed aquifer connections, transverse inflow/ outflow at selected points along the boundaries can be assumed (Muralidharan, 2006). Multi-purpose watershed management, using the drainage basin as the fundamental unit of management, and water management as an opportunity for state intervention to promote social and economic change need to be put into practice. Since success of agriculture depends on both the water and soil, their management needs to be given due importance. From the soil and water conservation point of view, the protection of soil surface with vegetation, the enhancement of the infiltration of rain water into the soil, and the control of running surface waters have been the priorities, all over the world, for water shed management. Additional concern has focused on the problems of water quality, especially, that related to the pollution of waters by agricultural practices, chemicals or salts leached by irrigation waters. The focus has also been to detect the conditions that govern when and where rain fall becomes runoff and soil is converted to water borne sediment. It is essential to keep in mind that the water shed management requires the application of hydro-physical, ecological and socio-economic logic and the integration of environmental management disciplines that too often operate in mutual isolation. These include: Hydrology, Water resources, Climatology, Forestry, Soil conservation, Nature conservation, Agronomy, Rural and landscape planning, Anthropology and Economics.

Groundwater Irrigation in Hard Rock Terrain

Occurrence of groundwater is a well-studied subject. In alluvial or sedimentary geological milieu, groundwater is found in permeable, generally granular, formations which act as storage reservoirs. In hard rock areas, there are also vast aquifers where water is stored mainly in fissured zone constituted by fractured rock (generally lime stones) and also weathered zones of semi-decomposed rock at the top of hard rock formations. Fresh basement is permeable only locally, where tectonic fractures are present. The understanding of the spatial distribution of these layers with their hydrodynamic properties allows developing methodologies both for the spatial distribution of these layers, for the assessment of groundwater resources and the modeling of groundwater flows at the catchment scale (Marechal et al., 2002). Marechal et al., study has clearly established the major role of weathering-origin fissures on the hydraulic parameters of hard rock aquifers; tectonic origin fissures having less important role. This information is vital, aspresently many prefer to drill bore-wells to depths beyond 900 to 1000ft, hoping to get higher yields. Granites of parts of Rayalaseema, Telangana and upland segments of Andhra, khondalites and charnockites of north Andhra, gneisses and schists of Prakasam district Quartzites of western Nellore and eastern Chittoor districts are an example of weathered hard rock aquifers. Lime stones and dolomites located in Cuddapah basin do also often have such conditions.

The economic problem is essentially to establish the best means to exploit the groundwater resource up to the point where the net returns are greater than the costs and, furthermore, where the net returns to any development are greater than alternative uses of the investment and recurrent resources. Thus, its usage compared to major surface irrigation scheme is manifold.

Analysts have to establish the most efficient means available for development whilst taking due account of the multiple objectives of public development policy. This plays a vital role when dealing with areas like Rayalaseema, parts of Warangal, Mahabubnagar, Medak, Ranga Reddy, Nalgonda and Nizamabad districts. It is quite likely that the form and extent of groundwater exploitation will vary depending upon whether the options are viewed from a public or private view point. In addition, in appraising investment options, social welfare function has to be maximized taking a different account of benefits. As such for overall socio-economic development of rural population of drought hit areas of Andhra Pradesh, one may have to step up resource inflow into minor irrigation works (especially groundwater exploitation programmes in conjunction with construction of percolation tanks, percolation canals, linkages between basins and sub-basins, check dams etc.).

Since groundwater has got direct relevance in rural development, those concerned with groundwater development have to keep in mind the inter linkage between irrigation, soil conservation, social forestry, overall socio-economic development of a region through agricultural based industries etc. So, one must keep in mind the interactions within the groundwater development before taking up any development work. For the benefit of planners, it is possible to categorize various projects according to their goals viz., maximum agricultural production; maximum return to investment; employment creation; and social welfare. Unfortunately, seldom are objectives set up in this way giving weightage to various project level programmes. Because of the importance of groundwater utilization, the future planning should have concentration on the overall optimum utilization of resources.

Where canal operation or rainfall is irregular and unreliable, the ability to exploit groundwater can ensure good irrigation development, by taking needed recharging of groundwater through appropriate technological interventions. It is paradoxical that at a time when the potential returns to reliable irrigation are shifting to a new level (a higher production function) as a consequence of scientific advance, evidence is increasing that major canal operation at times is subject to grave defects. This brings out the limitations of major schemes.

Groundwater development had proceeded at spectacular rates, from the first quarter of 1970s to beginning of 1990s, with good (but at times with staggered) public support, as individuals, groups of people could successfully implement various schemes with the definite hope of receiving benefits in a limited time.

Management of Tank, Canal and Groundwater: As one unit

If one can use groundwater judiciously (avoiding rat-hole mining of groundwater), it can offer other advantages over surface canal irrigation. Realization that groundwater is a limited resource despite annual recharge and should be carefully guarded, to satisfy our needs during periods of drought and not allowed to be squandered, is yet to dawn in the minds of our people. Indiscriminate drilling of bore wells is not the answer to the problem of restoring sustainable yields. Taking note of the present pattern of rainfall (a total of 20 to 25 rainy days of good intensity), water conservation through numerous large and small ponds is a much better alternative for storing rain water – it has to be stored where it falls – *in-situ*. As detailed earlier (Ref: A.P Plan Document). Our ancestors had a clearer conception of water availability and the need for conservation. They had, through their own labour, constructed at every favourable point a chain of reservoirs called tanks, any overflow from one at a higher level being fed to another at lower level and so on all down the course of the stream. These storage tanks, which were kept in constant repair by village communities through voluntary labour, are now in a state of decay (Geo-Forum, 2012) and mostly occupied for agriculture and housing purposes. Good health of tanks leads to better sustenance of groundwater schemes. Smaller pockets of suitable land can be more economically irrigated by groundwater than with surface systems. Normally a bore well system can be designed to suit any area and topography. Land, distant from rivers, can also be economically irrigated. The lower rates of distribution channels to irrigated fields, as compared to lining of surface water distribution channels need to be given due weightage while planning ground water reliant schemes. Wells can be located in upland areas or at the tail of canals where surface irrigation tends to be in short supply or delivered late (like in Prakasam district). It is also found that where wells recover drainage and seepage water from the irrigation system, the overall system efficiency of water use typically rises from about 50 to 80%.

Irrigation supply can be augmented using groundwater with the minimum disturbance to existing surface irrigation. Thus, the disruption to agriculturists present in major canal remodeling can substantially be reduced through groundwater development. Inadequate canal supplies especially in tail end areas during summer seasons can also be augmented with groundwater. In many parts of Rayalaseema even though reasonably good amount of ground water is available, it cannot be utilized for irrigation due to the presence of increased amount of dissolved salts. Efforts to improve the quality of these waters failed to yield proper results due to economic constraints. Since Rayalaseema is handicapped due to non-availability of perennial river inflows, it is necessary to enhance the quality of soils and groundwater in hitherto left out and unused zones. There is a possibility of utilizing some of the salt enriched waters for agricultural purposes by treating the waters with gypsum and by introducing drip irrigation. Since such an operation requires considerable amount of initial expenditure, probably beyond the limits of individual farmers, it is essential to take up organized rain water harvesting in these zones, with initial development based costs borne by the government. In this process, at times where saline groundwater is located we can utilize the same with proper blending of the same with the available harvested surface waters. This operation can be successfully used in brackish water zones located near the banks of Pennar, Tungabhadra and Handri rivers (viz., in Pamidi, Illur, Kallur, Dagguparti, and some villages in Kalyandurg and Kadiri mandals of Anantapur district and some areas in Kurnool district).

While recommending any irrigation scheme one should keep in mind that a single well will tap a limited aquifer without recharge or interconnection with other wells and the investment decision hinges on the question as to whether the sum of net benefits from using the groundwater, suitably adjusted for the time they arise, exceed the requisite margin of the development and operation costs over the life of the well. Even at the other extreme, where numerous farmers tap the same aquifer, we can control problems by providing single public tube/bore well in place of number of small open/bore wells to irrigate the entire land under question. In such a system, recharge is an important part of the resources. The optimum mixing of seasonal and perennial irrigation, the overall extent of rice and sugarcane cultivation and other decisions, in turn influence the amount of water available for irrigation and the drainage requirement.

From all the points mentioned above, since it is evident that groundwater exploitation is essential for developing the overall irrigation potential of various zones, especially where surface perennial sources are absent, one should take necessary steps to improve the recharging facilities to maintain water table level. Since in A.P. there are more than 3 million wells/bore wells, the planners should take necessary steps for repairing or constructing percolation tanks, percolation canals, check dams, diaphragm screens etc., through quality control mechanisms at field level. These should be given top priority especially in areas where hard rocks are present namely in Rayalaseema, Telangana, western parts of Prakasam, Guntur, Krishna, West Godavari, Visakhapatnam, Vizianagaram, Srikakulam and Nellore, not only to improve overall irrigation facility but also restrict damage to water table resulting in future desertification of areas. Unfortunately, rampant misuse of funds and meaningless subsidies that only help the influential segments of our society have led to failure of well articulated groundwater schemes and overall food production(Reddy, 2012a). For irrigation projects the manner in which groundwater may be used varies from project to project. In some cases, it may be used to bolster an erratic rainfall in order to ensure adequate yields. In others, it can be used to extend the cropping season or even to grow an additional crop during the dry season. Irrigation with existing surface water irrigation systems suggest a further range of possibilities, such as the use of additional surface water that, on its own, would be insufficient for a crop but would be adequate if supplemented by groundwater at either end of the season or at the peak. It may also be used to start irrigation earlier in a season before surface water and/or rainfall becomes available. This would result in the growth of a higher value crop or provide better land preparation than would otherwise be possible.

New Techniques of Exploration/Exploitation of Groundwater

Since organized groundwater exploitation seems to be an appropriate option as evidenced from the available statistics (65% of irrigation depends on minor irrigation), one has to give due importance to minor irrigation, in future irrigation programmes, which has been neglected during the last 20 years, due to improper use of exploitation techniques and poor quality of recharging structures and wastage of waters following age old flow irrigation even in drought prone tracts of the State and cultivating water dependant crops in every part of the State. Systematic groundwater exploitation requires introduction of new scientific methods. The basic data essential for starting an exploration programme can be had if there is proper coordination and linkage between different research and user organizations. After preparing photo geological and land-sat imagery maps and studying individual topo-sheets one should conduct hydro-geological and geophysical surveys, taking into consideration various geological parameters of the region. The geophysical surveys may include electromagnetic, shallow seismic refraction, radiometric and induced polarization surveys as per requirement, apart from the standard resistivity surveys. The integrated use of more than one geophysical method will enhance the percentage of success. However, the scientific inputs should not be confined to location of good aquifers. Scientific research should also help the users in exploiting only the required quantity of water that is essential in meeting his demands and share the remaining quantities with the neighbours, without destroying the aquifer health.

Many scientists and engineers talk of basin management. Unfortunately, the systematic mathematical modeling and laboratory experimental studies (analog/digital) that have been conducted for various river basins have not been refined in time and space, using continuous inflow of field data. Even the updated aquifer models are not practically made use of by the ground level technical staff, making the quality results confined to libraries and in-house data banks. While we advocate enhanced quality in research and better transfer of technology to benefit the end-users, we need to appreciate the strides made by devoted scientists in carrying out apt scientific studies during the last 20 to 30 years in better knowing of aquifer dynamics. Steps should be taken up for having real-time monitoring of basin/sub-basin dynamics (following a micro-basin and micro-watershed concept), at least in the hard rock areas to have a clear assessment of the basin potential. This would help in optimum utilization of sub-surface waters through bore and infiltration wells {the infiltration wells introduced by AP State Irrigation Development Corporation (APSIDC) in Bahuda, Cheyyeru and Swarnamukhi River basins yielded very good results, until the very sources have been damaged due to natural calamities and man-made errors}.

Even though we are taking necessary precautions before drilling a bore well, there is every possibility of getting poor yields from some wells due to probable non-tapping of fractured column. In such cases, controlled hydro-fracturing and blasting techniques may be adopted for revitalizing these low yielding wells. This option can be tried, under technical supervision of experts. In wells that are clogged due to presence of clayey and accumulated mud formations, one need to employ organized development/ flushing of well, a day after introducing Hexametaphosphate solution to dissolve the clay. Development should be continued at least for 3 hours to bail out dissolved clay and the chemical. Even after taking precautionary and curative measures we may not be in a position to supply copious amounts of water for irrigation, through bore wells. It is now established that groundwater regime is in a very bad state as both public and private sectors are following blind techniques in exploiting the groundwater by drilling bore wells to a depth of 1000 feet and within a distance of 5 to 10 feet from existing wells, giving least importance to "Fracture geometry" and "Interference" factor. It is essential to control this irrational and unscientific exploitation processes. Oft promulgated laws are not serving any purpose as there is no strict execution mechanism.

There does not appear to be any plan of research in respect of wise management of water resources. Research should be focused on understanding how water is transferred from the surface to the saturated zone below ground especially in the hard rock aquifers of south India? How does water move in fissured medium? What are the circumstances which enable storage and movement of large quantities of water in hard rock aquifers? We have to find answers to such questions. The process of aquifer recharge has to be better understood (Geo-Forum, 2012).

We have to take viable scientific techniques in revitalizing lakhs of defunct/failed/and sub-standard bore/tube wells (MAR, 2006), following the methodologies adopted by Andhra Pradesh Farmer Managed Groundwater Systems (APFAMGS) Project. Farmer participation in managing the aquifer, under the guidance of service oriented scientific/technical experts can alone save the situation. One also should use more sophisticated techniques for utilizing limited supplies of waters without transmission losses. To sustain existing irrigation and achieve at least 10% rise in created irrigation potential (from ~3.6 M ha to ~4 M ha), we should strengthen minor irrigation. We need to utilize sprinkler, drip and fertigation irrigation methods, on a compulsory basis, especially in upland and drought prone segments of the State. If regulatory mechanism is introduced to control the supply of water and arrest flooding of fields one can produce yields as much as 5 tonnes per hectare through sprinkler and drip systems as against the yield of 1.5 tonnes per hectare through flood irrigation. However, we should provide necessary education/training, incentives and regular maintenance to beneficiaries to achieve better benefits out of various quality sustaining schemes. We should also educate agriculturists about conservation of waters. We should practically demonstrate through experiments on stretches of land the disadvantages in using more waters than what is needed. Unless we alienate farmers from using age old practices of irrigation we may not achieve expected results. Hence, irrigation and agricultural engineers and scientists should make it a point to regularly spend a minimum amount of time in educating people, since there is no use of just talking about sophisticated technology without transferring the technology to the users. Once this is done we can dream of the day when we can successfully computerize every available data for optimum utilization of resources without damaging any system or source.

In my earlier presentation (Reddy, 2005), I have tried to stress the significant changes noticed in the groundwater dynamics due to climate change, basins scale water balanced changes, river flow regulation, sediment fluxes, chemical pollution, microbial pollution and bio-diversity changes. It was advocated that the need for strict quality control in planning, designing and erecting artificial recharging structures should be given top priority. I also stressed the need to have a monitoring system that can ensure quality control both in planning and executing various time bound developmental programmes. In an international workshop, stressing the deteriorating scenario, I suggested a radical approach (Reddy, 2006) for better management of water resources. I stressed the need to regulate irregular river flows, random introduction of artificial recharge structures without understanding the basin dynamics and aquifer geometry. It was stressed that we have to strictly control over pumping of subsurface water resources, by introducing controlling devices into the pumping and distributaries systems that can automatically control water usage beyond permissible limit. It was also advocated that arresting of the large scale mining of river sand-beds need to be strictly implemented as sand mining has converted number of rivers into free flowing structures resulting in loss of water as run off without charging the adjacent aquifers. Unfortunately, none whose decision can effect a change in the right direction, has given any weightage to those suggestions, as they seem to be aware of these facts but have limited freedom in implementing them, due to various socio-economic constraints and political compulsions. Due to various ad-hoc short term decisions by the implementing agencies, due to political and socio-economic compulsions, we have noticed significant deterioration of minor irrigation sector.

As pointed out by B.P. Radhakrishna (Geo-Forum, 2012), groundwater is a manageable and more efficient source of irrigation. There is no problem of water logging and no major water loss (amounting to as much as 50% of the water released at head works) through evaporation and seepage. Since small and marginal farming community basically depends on this source and all those living in uplands also depend on this source every care is needed to protect it and not allow it to get depleted. For this, groundwater sanctuaries should be established and be equipped to keep actual record of rainfall and the flow generated at various intensities. Methods of catching and storing this rainfall both on the surface and underground should be demonstrated to the farmers by technical experts. Efficacy of different types of structures in intercepting rainfall and allowing it to seep underground as result of natural process as well as artificially injecting excess water to recharge groundwater reservoir should also be demonstrated at the field level. Maintenance of accurate records of changes in water level in observation well will provide necessary checks in evaluating the efficacy of the different practices adopted. All aspects of rain water harvesting and water conservation should be tried. Scientists of all disciplines, pooling their research capabilities should be in a position to find solution to problems of water availability and utilization. "Water is a crop, a resource to be cultivated, nurtured and harvested over long periods of time".

DRAINAGE AND CONJUNCTIVE UTILIZATION OF SURFACE AND GROUND WATERS

The upper groundwater - that exists near the groundwater surface - is often treated as though it was a separate body whereas in the great alluvial plains, it is essentially part of a continuous system. It is this upper ground water which is involved in drainage and, in some cases; it is cheaper and more effective to reduce the water table level using wells rather than to use conventional methods. If the pumped water can be used for irrigation, then drainage objectives can be met at virtually no cost.

Introduction of large scale irrigation by canals had led to serious problems of salinity and water logging in almost all canal commands of irrigation projects in the semi-arid regions of India, including Andhra Pradesh. This is because of the disturbance caused to hydrologic equilibrium of groundwater basins after the introduction of canal systems. The command areas affected by water logging and salinity in A.P. are estimated to be ~0.3 and ~0.1 m Ha, respectively. The water logging and salinity problems not only cause severe physiological crop damage, but also increase cost per unit of crop production and decrease farm income. These problems can be overcome by effective design and installation of surface and sub-surface drainage systems for the removal of salts and excess water from the area (Srinivasulu et al., 2002). Regrettably drainage is still very much the "poor relation" in the vast irrigated areas of developing countries, including our own. Even at the planning report stage the case for irrigation is much more easily made than that for drainage. This is partly due to the fact that the response of the crops to various degrees of drainage is not yet clearly known with precision and, in fact, the complex relationship between soil texture, soil and water chemistry, depth to the water table and tolerance of various crops to adverse conditions may present too many variables to researchers for any practical ground rules to be developed. And yet, there are many thousands of hectares of agricultural land being lost every year due to inadequate or non-existent drainage. One can bring under irrigation many areas located in the coastal belt of A.P. that are submerged under drainage water, by taking appropriate developmental operations. In-land, poor drainage has resulted in saline efflorescence leading to inferior quality of soil. It is relevant to state that even though the drainage problem has come down in the coastal tracts, due to less and irregular availability of waters for irrigation (due to various natural and man-made problems, especially in the last two to three decades), we need to give due importance to drainage problem as once an irrigation system has been established, the subsequent cost of drainage is huge. Everyone knows about water logging problems encountered during 1970s and 1980s in Sriram Sagar, Nagarjuna Sagar and Tungabhadra Projects. Since there will be some problems, especially due to cloud burst related floods and flash floods (which would submerge lands located in the river basins and the coastal belt), for future projects the trend will have to be towards installing drainage together with the irrigation system. This should be implemented strictly to avoid many hazards. In water-logged areas, due to poor drainage facility, long term use of waters without careful control of leaching will lead to a salt builder in the top soil. In these areas, water table levels must be depressed so that there cannot be reverse, upward movement of salts in solution in the capillary water. Further, even where water table is deep and salt is leaked out of the root zone, there is a danger that following the rain or heavy irrigation, salts will go into solution and be drawn into the root zone when sufficient insulation occurs. Conjunctive use of surface and ground waters is the only solution especially in those cases, where there is a drainage benefit from groundwater pumping. However, in the coastal belt, it is essential to take needed precautions before carrying out water table lowering operations, as uncontrolled over-exploitation of groundwater would lead to saline water intrusion from the adjacent sea, making both the groundwater and the land useless for cultivation. The unscientific aqua culture operations, during 1990s have damaged considerable segments of the coastal belt. While we encourage aquaculture, the owners need to be educated regarding organized aqua culture to reap higher production, without affecting the ground and surface waters and the environment. In addition, we have to also make note of the impact of Oil & Gas extraction in the K-G basin. These operations have resulted in subsidence of the land and pollution of the groundwater. If the proposed extraction of shale gas in this basin is allowed, this region will face number of water quantity and quality problems affecting significant population of the region (Reddy, 2013). Even though conjunctive utilization of surface and ground waters will be beneficial, till recent past at all levels the possibilities of introducing this are widely ignored. Due to absence of liaison between irrigation engineers and groundwater specialists, there is considerable absence of understanding between departments operating with surface water and those involved in groundwater exploitation. Planning engineers seem to believe in giving preference for the water which can be seen, that is, water stored in a surface reservoir behind a dam. This has resulted in uncontrolled groundwater exploitation (due to absence of quality control mechanism) and inadequate conjunctive use of surface and ground waters. Fortunately, such a negative mind set has taken some percentage of beating in the recent past as majority of the small, marginal and middle class farmers living in upland areas, drought prone zones and canal tail end zones realized the importance of optimum utilization of both surface and ground waters. It is heartening to learn that efforts made by Indo-Dutch Network Bridging Project (Srinivasulu et al., 2002) in addressing drainage related problems in Nagarjunasagar project right canal command and Krishna western delta, yielded excellent results. Based on the design criteria developed (grid-iron pattern of layout, 15 pipes were laid using flexible corrugated perforated P.V.C pipes and two types of envelop materials), sub-surface drainage systems were installed in Konaki and Uppugundur villages of Prakasam dist. These drainage systems have helped in reclaiming the water logged saline lands (Srinivasulu et al., 2002).

Management of Freshwater-Seawater Interface in Coastal Corridor

The use of coastal aquifers as operational reservoirs in water resource system requires the development of tools that make it possible to predict the behavior of the aquifer under different conditions. Studies on the freshwater- saltwater interface either in steady state or transient conditions have become necessary in designing and planning groundwater systems in coastal areas. Along a coastline, freshwater “floats” atop denser seawater wedge that dips landward beneath the coastline. On islands freshwater floats as a lens over the transition zone that borders pure seawater. It is the density difference between the fresh and seawater that causes the freshwater to float above the transition zone at and below sea level and is integral to understanding why seawater intrusion occurs. This freshwater- seawater balancing act is governed by what is called the Gyben-Herzberg Relation. It is a physical relation based on the difference in densities of seawater and freshwater. Due to this difference, small changes in freshwater level or head can effect large changes in the transition zone. It is noticed from different studies that for every foot drop in head (water level) the transition zone immediately below will rise by 40 feet. Therefore, even very small changes in the water level (caused by droughts or over drafting the aquifer) can cause a significant intrusion of seawater (Elango, 2006). For example in the coastal belt, with time, due to Global warming/ the fertile lands could be affected by sea water rise. In such zones, including fertile Konaseema, we need to see how we can avoid inundation and back water surge and how to arrest land ward movement of subsurface saline ingression. The complex hydrological and hydrochemical conditions restrict the utilization of groundwater resources. The shape of the water table and the depth to the fresh/saline interface are controlled by the difference in density between fresh water and salt water, the rate of freshwater discharge and the hydraulic properties of the subsurface system. A series of marine transgressions and regressions in the past have greatly influenced the depositional environment of Konaseema and East Godavari delta. The geomorphic evolution of delta has controlled the occurrence and nature of aquifers. The area is characterized by presence of palaeo channels, palaeo beach ridges. Some of the drains are believed to present palaeo channels while some more are concealed in the delta. The exploratory wells of CGWB have brought to light that the wells beyond 100 m are saline. Wells constructed in the adjoining areas also brought in to light that deep wells are saline. The fresh/saline water interface at depth may vary considerably. For instance at beach ridges where thin shallow fresh water pockets persist, the saline water occurs at very shallow depths. In palaeo channels and close to river, the saline water may occur at a depth below ranging from 8 to 70 m (Rao, 2002). Since this area is called as “Rice Bowl of A.P”, we need to educate the farmers regarding exploitation of groundwater, to avoid damage both to the aquifers and to the fertile land. Similarly the Krishna and Penna Deltas need to be protected, to achieve food production targets. It has been observed from coastal well monitoring that the salinity problem is prevalent all along the coastal corridor of A.P.The salinity problem has also significantly damaged the eco system of the famous Kolleru Lake.

As water drains toward oceans and seas, it slowly carves networks of valleys and channels. These drainage networks form in part due to erosion by surface runoff, a process that involves a complex, hard-to-disentangle feedback: Runoff flows share the topographical landscape, but that landscape shapes the paths of runoff flow. Drainage – network formation is also partly due to ground water flows. Precipitation absorbed by the ground tends to settle into subsurface reservoirs, or aquifers'. If an aquifer is pierced by a deep channel- one whose lowest point sits below the water table – then ground water can seep into the channel and, in the process, erode the channel valves. This seepage erosion causes low lying streams to widen and lengthen over geologic time scales. Unlike in the hard rock terrain, as the flow dynamics in aquifers is in most cases independent of the over lying topography, the seepage fluxes are relatively straight forward to model. Such seepage flows leave a distinct, and seemingly universal, finger print on the complicated patterns seen in many drainage networks (Smart, 2013). This information is very useful in understanding the coastal Godavari and Krishna basins aquifer dynamics and need to be taken note of in developing aquifer models. NGRI scientists have shown that the saline ingression can be arrested by sub surface screens that open one way towards sea, arresting saline water ingression while allowing fresh water from the land to flow in to the sea. They have also shown how sand dunes present along the coast could be fortressed to arrest sea tide inundation of coastal inlands. Since interactive scientific research, adopting a holistic approach is the need of the hour, research organizations located within the state should be encouraged to solve area specific problems, by parallel development of practical solutions (using field level trial and error exercises) and highly innovative scientific research based on integration of theoretical and experimental modeling.

LIFT IRRIGATION SCHEMES

Lift irrigation is a method of irrigation in which water is not transported by natural flow (as in gravity-fed canal systems) but is lifted with pumps or other means.This form of irrigation is in vogue since the last 40 to 50 years. It is effective as one of the important components of minor irrigation.

Chalamaiah (2002) has pointed out that the present environment safety movement may not allow, in the next couple of decades, taking up of major and medium irrigation projects involving huge areas of submergence, resulting in rehabilitation problems, annihilation of rare species of flora and fauna and disturb the harmonious balance of nature. In addition, the well accepted slogan "catch and store every drop of rain water, in-situ" will not allow sufficient flows into the rivers, making major irrigation structures heritage monuments (except when cloud bursts and floods occur). The Lift Irrigation Schemes (LIS) are small and spread throughout A.P. State both spatially and temporally (there are more than 10,000 LIS in A.P.), whereas the major and medium irrigation projects are concentrated in site specific areas. Construction of LIS will result in more equitable development of the State, as seen from the success of APSIDC managed LIS. The gestation period for LIS is comparatively small. The management of LIS, like GW schemes, can be turned over to the beneficiaries easily. Involvement of earth scientists of APSIDC, as social scientists (since 2005) resulted in successful operation of not only APSIDC LIS but also those built by the irrigation department. However, steps need to be taken to avoid frequent mechanical failures and indiscriminate pumping of water from the surface water bodies, using free electricity.

There is no submergence of cultivable lands under LIS; whereas 15% to 20% submergence of command area is required in flow irrigation projects. Regenerated flows or very lean flows can be used for LIS. These schemes, like GW schemes, do not create environmental or inter-state problems, as they do not involve submergence. Wherever large projects involve submergence and environmental problems, innovative strategies can be used to harness water resources. To illustrate, several small dams can be constructed to avoid submergence of large areas, or reservoirs can be built on the mainland to retain the storage capacity. By pumping river waters in to these reservoirs, vast stretches of dry land can be irrigated. However, the efficacy and sustenance of such structures depend on quality construction and regular maintenance; including de-siltation of reservoirs and timely pumping of waters in to the distribution channels. One of the main inputs in the LIS is the electricity, which is very scarce and costly. However, a judicious planning can help the beneficiaries, in overcoming this problem. One of the options is to introduce solar/wind energy to lift waters both from bore wells and from surface water bodies (tanks, ponds). In this context the recent initiatives both in Karnataka and A.P states need attention. In Karnataka the state government has launched a plan to boost the lift irrigation projects in the state wherein it will install solar panels on irrigation canals to generate power. In the first phase, this project would be implemented in Yadgir, Raichur and Bijapur districts and then extended to other districts. The Karnataka government took the initiative inspired by the success of a similar project implementation in Gujarat where the villages are getting uninterrupted power supply.

Since solar energy usage is encouraged by the Central government and substantial initial cost of erecting solar reflectors/panels and accessories are covered through subsidies, the state government should encourage solar energy usage. Since conjunctive utilization of surface and sub-surface waters can meet water needs of the beneficiaries it is advisable to have bore wells in appropriate locations within the LIS ayacut and use both the forms of schemes to ensure successful growth of agriculture/horticulture.

PRESENT SCENARIO

Repeated droughts have significantly increased the migration of rural people to urban areas. As mentioned earlier, in our country 65% of agriculture depends on minor irrigation. Due to illogical negligence of minor irrigation, even in zones that have no river water supplies, small, marginal and middle class farmers have taken up the risk of investing in wells and bore wells, taking loans at a very high interest rate. After initial growth, negative signals have surfaced in the form of declining groundwater levels, reduced yields and in some cases even drying up of wells. Concerned of this issue, some NGO`s (under the guidance of APFAMGS) have been providing (in parts of Andhra Pradesh) knowledge to the farming community to manage their groundwater resources optimally and initiate various steps to contain and manage this alarming situation. Regular monitoring of groundwater levels and estimation of groundwater balance has provided the farmers the understanding on the need for enhanced groundwater recharge. It is explicitly proved by these NGO organizations that the vicious circle involving drying up of wells, reduced irrigation, increased migration of rural farming community need to be addressed by an integrated programme of Managed Aquifer Recharge (MAR) that will help rebuild groundwater levels and provide farmers round the year farm dependent labour. It is clearly established by APFAMGS that participatory hydrological monitoring and crop water budgeting can yield very good results. Extraction of water from the deeper aquifer, which has led to financial insecurity to the farmers, has been standardized due to the better understanding of the recharge pattern of the deep aquifers. Uncontrolled groundwater extraction leads us to believe that withdrawal of groundwater in the basin is largely from static storage components. The static storage is the deeper and older water that lies below the dynamic component (Palaeo-water). Abstraction from this storage results in groundwater mining. Groundwater mining is never sustainable. It is mainly responsible for the farmers' problems and miseries in different parts of the State. In the absence of any understanding on what portion of the dynamic and static storage need to be allocated for use, it will be appropriate to ensure a large portion of the dynamic storage. It has to be always kept in mind that withdrawal from static storage will have large environmental repercussions. Towards reversing groundwater decline an artificial recharge strategy is to be initiated as part of Integrated Water Resource Management by utilizing natural sub-surface storage wherever technologically, economically, environmentally and socially feasible. The most common avenue is to store water in the sub-surface for later use as this usually being achieved by allowing water to infiltrate the sub-surface via open wells or by injecting water via bore holes into the aquifer. This is a form of water conservation, in that the water that would otherwise be lost through evaporation and evapotranspiration from surface water structures is saved. This strategy on artificial recharge will allow planners to include artificial recharge as a feasible water development option when it comes to assessing, planning and managing water resources (MAR, 2006).

The proposed strategy for rejuvenation of the groundwater requires optimization of all the rainfall falling within the hydrological basin by harvesting bulk of the peak flows using the surface irrigation structures, watershed management structures, abandoned open wells, bore wells and transferring it to the sub-surface as aquifer storage for later use. Artificial recharge programme shall require cooperation between all the sections of the farmers. Artificial recharge programme will make available additional groundwater resources (that have been artificially recharged) to the entire drainage unit that can be accessed by a number of potential users who are located on or near the aquifer. High levels of cooperation will be vital in order to prevent the misuse of the new found resource. Artificial recharge programme is also a significant tool in water conservation and wise use of groundwater.

As demonstrated by APFAMGS, viability of

Managed Aquifer Recharge (MAR) scheme depends on a clear understanding of the various potential issues and an ability to deal with them at the planning stage itself. The critical issue in hard-rock aquifers will be the nature of the sub-surface flow. The heterogeneity of fractured aquifers offers the additional complication to the participating farmers as to "where is the water going to?" and "where from it can be best re-captured"? Fortunately, some farmers have good understanding of the behavior of groundwater in wells/bore wells and as such they are well equipped to deal with such issues. Such farmers, if trained by service oriented scientists can act as extension officers and orient/train other farmers in making MAR successful in every aspect in different parts of the State. The objectives of MAR scheme must be clearly articulated with participating farmers and an approach to assess its success defined such as defining key performance indicators. Since the scheme is implemented to address the localized water-related problems of groundwater over-exploitation leading to steep decline of groundwater level this will probably continue to be the prime indicator to be monitored. MAR should address the larger issue of improving the groundwater balance from a deficit basin to excess basin with reversal in the groundwater level decline. This will address the other issues related to migration of farmers as the farming operations will be for longer periods. The rationale for a MAR project will be fully justified when the costs of extraction of groundwater is considered for comparison. Groundwater development has become uneconomical as the costs go beyond the reach of small and marginal farmers (at times even middle class farmers). Although the costs are private, yet they have large social and economic significance. Private indebtedness has significant effect in the overall agriculture production in the area. The overall costs of MAR operations are disproportionately low when compared with the capital cost of conventional surface water supply alternatives, especially those involving the development of new reservoirs, laying down canals, compensating farmers from inundated area and on pipelines cost. The project will be environmentally appropriate as this will not inundate new areas as well as will not get localized to small area. Since it is established that the social involvement (farmers participation) is the main criteria for successful functioning of various schemes, both private and public, it is essential to strengthen the cooperative society concept rather than implementing the recently promulgated law – "Water is public property", as this suggested step can de-motivate the farmers (Reddy, 2012). However, the basic objective behind the law could be achieved if the farming community follows cooperative norms on a voluntary basis, without interventions by either politicians or Government field supervisors, and receive help from experts in the form of technically relevant and viable solutions (Reddy, 2012a).

The above details are relevant in the case of groundwater usage in the hard rock terrain. Groundwater is also available in soft rock zones present along Godavari graben (parts of Warangal, Khammam, Karimnagar, Adilabad and West Godavari districts). In these areas, APSIDC has constructed number of tube wells extending to depths of 200 to 300 meters using rotary and reverse rotary drilling technology. These tube wells constructed more than 35 years back to serve tribal and other economically deprived communities have, at many places, deteriorated due to various defects including damage to casing pipes, gravel pack, etc. Since each tube well can irrigate nearly 40-50 acres and as it is the present policy to insist on farmer maintenance of the wells, it is advisable to restore defunct tube wells by constructing new tube wells using corrosion resistant casing pipes and proper gravel packing and development (utilizing necessary input from different geophysical well- logs). Before constructing new tube wells, as cost of drilling, construction, and development would amount to about Rs.8 to 10 lakhs, it is advisable to scan the existing tube wells structures by using in-hole close circuit TV to identify the sources of structural weakness. This information along with information regarding quality of waters would help in better establishment of appropriate new tube wells. Once the wells are made productive, the department can ask the farmers to form a co-operative society to better utilization of good quantity of waters, using new irrigation and cultivation techniques, by making 100 acres as a viable unit. Such a categorization can improve the output and save individual farmers from various cultivation and marketing problems (Reddy, 2012a).

Even though scientific and technological development can change the overall life style of the tribals we can only help them by providing needed help in their day-to-day farm and forest development, without encroaching into their private life. For getting better produce from their agricultural farms and orchards, we have to provide continuous flow of waters. APSIDC, to the extent possible installed both LI and GW schemes in different tribal tracts located all along the Godavari basin to provide waters to the tribal lands. Since mid 70s the APSIDC has taken up number of LI schemes in tribal areas of Adilabad, Karimnagar, Khammam, Warangal and West &East Godavari districts(In the recent past tribal tracts present in Vizianagaram, Visakhapatnam and Srikakulam are being developed, by developing hard rock aquifers).

Since there is sufficient amount of surface and sub-surface flows in main Godavari and its tributaries, there is every possibility of taking up many more LI schemes in different zones or restoring the defunct LI schemes. The progress under GW schemes ,which was rather limited due to various logistic constraints improved during mid 1970s and 1980s. The efforts led to installing tube wells in Chennur, Asifabad, Mancheriyal and Siripur regions of Adilabad; Mahadevpur and Peddapalli regions of Karimnagar; Eturunagaram, Laknavaram zones of Warangal; Sathupally and Ashwaraopet of Khammam; Chintalpudi areas of west Godavari and in some parts of East Godavari. Since majority of the rocks in the Godavari basin are softer or medium hard and as there is sufficient amount of recharging facilities, one can successfully commission number of tube well schemes. The quality of ground waters, except in some zones of Eturunagaram and Sathupally, are reasonably good and can be directly used for irrigation purpose. The waters from Eturunagaram and Sathupally are also capable of raising wet crops which can withstand some quality deficiencies. Since major irrigation facilities are being contemplated across Godavari, efforts need to be taken to ensure sustenance of tribal welfare in these segments of A.P.

WHAT IS NEEDED?

Excellent scientific research has been carried out by different organizations. CGWB has brought out "Aquifer Atlas" of different States, after dedicated four decade long scientific pursuits. They have established observation wells in different parts of the state and are generating ground water data using piezometers, in co-ordination with SGWD. NGRI has carried out significant scientific research to address both quality and quantity aspects. It has also collaborated with Netherlands, Germany and France in building digital models of hard rock aquifers and basin dynamics. Scientists have demonstrated the importance of artificial recharge and rain water -harvesting structures, in parts of Anantapur, Kurnool and Nalgonda districts. Scientists have also developed data acquisition models through tank experiments. APSIDC has taken up intensive groundwater schemes, starting from mid-1970s to help small and marginal farmers. Earth scientists of APSIDC scientific wing have successfully restored, in the recent times, a significant number of abandoned bore wells, through area-specific structural designs in parts of Medak, Ranga Reddy and Mahabubnagar districts. APFAMGS has successfully demonstrated the efficacy of Managed Aquifer Recharge (MAR) technique, through farmer participatory involvement in different segments of the state including parts of Chittoor district. Different universities have collected data from different parts of the state and studied in detail groundwater quantity and quality aspects. Unfortunately, all these scientific achievements have not resulted in large scale replication and wider application at the field level. Absence of a viable monitoring mechanism has resulted in sealed box knowledge and archiving of the success stories/results. The intra- and inter- departmental recommendations by the scientific and technical community have only produced heaps of information/data. For a wider application of the isolated scientific endeavours, scientists need to interact with each other at the field level to verify the efficacy of their studies and importance/ limitations of their results and provide answers to the doubts expressed by the end users - Farmers. For this, seminars and workshops need to be organized at the field level. In addition, the groundwater experts should develop a single "science Forum" to project the importance of their scientific endeavours. They need to impress upon influential lobbies the necessity to strengthen groundwater restoration schemes. In this aspect, one should appreciate the significant services being rendered by Bengaluru based "Water Portal", Institution of Engineers, Indian water resources society and Indian Association of Hydrologists.

Research institutes that are carrying out significant research on hard rock aquifers need to adopt villages that have witnessed large scale farmer suicides and practically demonstrate the importance of organized scientific research in exploring, exploiting, conserving, storing, transporting and using ground waters. By adopting villages our scientists will be motivated to bring out target oriented results in a time bound duration .This will also expose them to the ground reality. As pointed out by Radhakrishna (Geo-Forum, 2012), the one opportunity for earth scientists to come into close contact with villagers/farmers and be of service to them is in the field of groundwater. At present majority of earth science community is least prepared to communicate information and resolve the doubts about availability of groundwater and its wise management. Sporadic attempts (listed above) to recharge aquifer system, as isolated actions, are not of much use as water resource management is full of complexities. Water resource management through adoption of better practices should be a field of most advanced and practical research. Advanced scientific research to understand basin dynamics in time and space and aquifer geometry, structure and its dynamics need to be studied through digital modeling followed by field checks. Field checks need to be carried out by understanding the physical significance of every input parameter and theoretical solutions. Such an approach can alone help in solving area specific problems. It is essential for a researcher to properly identify an attribute- some trace of growth of natural drainage networks in real time, to use as a bench mark. As such a researcher needs to find a property (associated with area specific ground water regime) that is, unambiguously measurable and theoretically understandable. In addition to such high quality scientific endeavors, we need to encourage development and usage of techniques / designs, using experience gained through field exercises.

As successfully demonstrated by APFAMGS and some NGO`s, the scientists can take up appropriate field level programmes, which while providing employment opportunities, can ensure improvement of groundwater recharge during the period of abundance. This could be achieved by using abandoned open wells and bore wells for building the groundwater. Farmers do not want our sympathies. Many of them, even while undergoing considerable stress do have self-respect and only look forward to technically sound solutions and timely supply of quality inputs (including water) to overcome their problems. As scientists, it is our duty to empathize with them. Empathy in the highest form is when we adequately know what others need, whom we can help with their needs. Empathy is when we forego judgment for understanding, when we move beyond reacting and ready to take action when we discover answers. People with the greatest empathy are those scientists who know how to listen to what is not spoken by the farmers. Since success of minor irrigation schemes, especially groundwater based, needs focused and committed involvement of all categories of earth scientists (theoretical, lab and field), they need to be motivated to take up societal important groundwater schemes, as a team. The team of scientists involved in such successful exercises should be encouraged and rewarded at par with those who publish, using lab experiment based data and theoretical modeling. Many of the bright and service oriented researchers, who wish to practically prove the efficacy of their research capabilities, are discouraged by the present science policies practiced in the research institutes. Their contribution can be evaluated by assessing their services to the farming community. In various international and national conferences it was agreed that more could be done to bridge the divide between the scientist (internally between scientist and scientific managers), policy maker and practitioner. The communication between water management researchers/ policy designers and practicing environmental managers must become more of a two-way interaction. We need to come out of the presently adopted policies of basically rewarding applied, lab oriented and theoretical scientists for published papers and neglecting the innovative field scientists/practitioners for societal important results (labeling them as routine exercises). However, since the farmer and the Govt want wellbeing of the agriculture economy, the practicing scientists group (containing all the three categories, as a team) should be encouraged to steer future workshops/ meetings further from independent academic model and more into collaborative investigations. By organizing mutual training workshops, practicing researchers, teaching and lab oriented scientists and policy makers would come to know about what to do (under what constraints) and how they could assist in achieving positive results. This would help all the concerned to work together towards more practical, more innovative and more integrated solutions. If our agriculture base has to be saved we need to strengthen interactive scientific research and viable sustenance schemes and strengthen farmers' intervention in saving their own water resources using co-operative sharing norms.

The state government has to 1) Find ways and means to IMPLEMENT Jayathi Ghosh Committee's recommendations; 2) bring on to one platform scientists and technical experts from different scientific organizations, state irrigation and groundwater departments, organizations like APFMAGS, University faculty, scientific societies; 3) identify quantity and quality problems in tribal lands and introduce needed curative and preventive measures, without destabilizing their basic way of living; 4) rehabilitate defunct and damaged irrigation and percolation tanks in drought prone regions, on priority basis and introduce new surface and sub surface storage reservoirs to store run off waters, after a storm or a cloud burst, and utilize the stored waters through organized quality management; 5) introduce/ restore small lift irrigation schemes; 6) introduce alternate energy sources (solar and wind) to lift only needed quantity of waters from tanks/ ponds and bore wells and distribute them equitably to entire ayacut; 7) introduce as a mandatory irrigation technique, both sprinkler and drip irrigation and encourage area specific cropping pattern in place of rice and sugarcane, especially in drought prone segments of the state; 8) encourage farmer participation management by adopting APFMAGS initiative; 9)Government should form a high level committee at state level and sub committees at district level. Both the committees should have administrative, scientific, engineering, academic and socio-economic experts from government and non government segments of our society, in addition to people's representatives, basically to take apt administrative and technical measures to ensure smooth functioning of various schemes. The target of adding 10 lakh hectare irrigation potential, in a decade (envisaged in 2005) should at least be made a reality in the next 5 years.

CONCLUSIONS

It is evident that our agriculture economy can be sustained by judiciously using both the surface and sub-surface waters. Due to global warming related monsoon vagaries, it has become difficult to forecast in a systematic way the pattern of monsoons. This has resulted in considerable problems to the farming community, especially the small and marginal. To sustain their agricultural practices, farmers, without proper technical support, have drilled bore wells in a random way leading to debts and suicides. Presently considerable focus is on major irrigation. Unless minor irrigation schemes are encouraged, our agriculture dependent economy would further deteriorate as perennial river waters are not accessible to a significant segment of farming community. To overcome various major irrigation based problems (environmental and socio-economical), it is essential to strengthen the minor irrigation, especially the tank and groundwater based schemes. These schemes can be made successful if the farmers are allowed to participate from the planning stage, as demonstrated by APFAMGS. Since the state govt. is fully aware of the importance of Minor Irrigation, needed steps have to be taken to implement recommendations of Jayathi Ghosh Committee, on a priority basis.

Earth scientists need to translate the acquired knowledge to the end-users by demonstrating the efficacy of their scientific endeavours (a judicious combination of theory and practice) directly to the farmers at the field level. These scientists should be encouraged and motivated by the management to take up such steps as a team to meet both short term and long term irrigation needs.

The movement to give due priority to minor irrigation can be made successful by creating an environment where researchers, practitioners, policy makers and NGO activists meet, listen to and communicate one with the other. This is not easily achieved unless those engaged in problem –solving research and those in practical environmental improvement develop greater contact, greater mutual understanding, and more interaction. APFMAGS, NGRI and APSIDC initiatives have yielded good results as all the concerned have given due weightage to all the factors essential to make a minor irrigation scheme successful.

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