REPORT OF
THE WORKING GROUP ON
WATER DATABASE DEVELOPMENT AND MANAGEMENT

FOR
THE 12TH FIVE YEAR PLAN
(2012-2017)

PLANNING COMMISSION
SEPTEMBER, 2011

Table of Contents

Executive Summary

REPORT

LIST OF ABBREVIATIONS

1.	ACWADAM	Advanced Centre for Water Resources Development and Management
2.	AIBP	Accelerated Irrigation Benefit Program
3.	APFAMGS	Andhra Pradesh Farmer Managed Groundwater Systems
4.	ARG	Automatic Rain Gauge
5.	AWS	Automatic Weather Stations
6.	BCM	Billion Cubic Meters
7.	BIS	Bureau of Indian Standards
8.	CADA	Command Area Development Authority
9.	CGWB	Central Ground Water Board
10.	CMIS	Coastal Management Information System
11.	CoI	Census of India
12.	CPCB	Central Pollution Control Board
13.	CSE	Centre for Science and Environmental
14.	CSIR	Council for Scientific and Industrial Research
15.	CWC	Central Water Commission
16.	C-WET	Centre for Wind Energy Technology
17.	CWPC	Central Water and Power Commission
18.	DSS	Decision Support System
19.	DSS(P)	Decision Support System(Planning)
20.	DSS(RT)	Decision Support System(Real Time
21.	DWLR	Digital Water Level Recorder
22.	DWR	Doppler Weather Radars
23.	ET	Evapotranspiration
24.	FAO	Food and Agricultural Organisation
25.	FES	Foundation for Ecological Security
26.	FMO	Flood Meteorological Offices
27.	GDSQ	Gauge, Discharge, Silt and Water Quality
28.	GEC	Groundwater Estimation Committee
29.	GIA	Gross Irrigated Area
30.	GIS	Geographical Information System
31.	GPRS	General packet radio service
32.	GUI	Graphical User Interface
33.	GW	Ground Water
34.	HDA	Hydrological Design Aids
35.	HDA(SW)	Hydrological Design Aids (Surface Water)
36.	HIF	Hydrological Instrumentation Facility
37.	HIS	Hydrological Information System
38.	HO	Hydrological Observation
39.	HP	Hydrology Project
40.	HYMOS	Hydrological Modelling Software
41.	ICAR	Indian Council of Agricultural Research

42.	ICSSR	India Council of Social Science Research
43.	IISc	Indian Institute of Science
44.	IIM	Indian Institute of Management
45.	IMD	Indian Meteorological Department
46.	ISRO	Indian Space Research Organisation
47.	IT	Information Technology
48.	IWIN	Isotope Fingerprinting of Waters of India
49.	LUS	Land Use Statistics
50.	MI	Minor Irrigation
51.	MoRD	Ministry of Rural Development
52.	MoWR	Ministry of Water Resources
53.	MoU	Memorandum of Understanding
54.	NCIWRD	National Commission on Integrated Water Resources
55.	NDC	National Data Centre
56.	NEERI	National Environmental Engineering Research Institute
57.	NFHS	National Family Health Survey
58.	NGO	Non-Government Organisation
59.	NGRI	National Geophysical Research Institute
60.	NIA	Net Irrigated Area
61.	NIC	National Informatics Centre
62.	NIH	National Institute of Hydrology
63.	NRSC	National Remote Sensing Centre, Hyderabad
64.	NSDI	National Spatial Data Infrastructure
65.	NWRIC	National Water Resources Information Centre
66.	PET	Potential Evapotranspiration
67.	PHED	Public Health Department
68.	PM	Penman–Monteith
69.	PMP	Probable Maximum Precipitation
70.	PRL	Physical Research Laboratory, Ahmedabad
71.	PSI	People’s Science Institute
72.	QPF	Quantitative Precipitation Forecast
73.	RET	reference evapotranspiration
74.	SEZ	Special Economic Zone
75.	SGWB	State Ground Water Boards
76.	SPCB	State Pollution Control Board
77.	SWDES	Surface Water Data Entry System
78.	TRG	Telemetered Automatic Rain Gauges
79.	UGC	University Grant Commission
80.	WG	Working Group
81.	WISDOM	Water Information System Data online Management
82.	WMO	World Meteorological Organisation
83.	WRD	Water Resources Department
84.	WRIS	Water Resources Information System

Executive summary

1. Background

As part of the preparation for the XII Plan the Planning Commission decided to constitute, for the first time, an expert group to review the present system of collection and dissemination of water-related data and to suggest improvements.

The 17-member Working Group (WG) consists of eight senior officials from the CWC, CGWB, NIC, WRD Government of Maharashtra and principal Government research organizations dealing with water-related issues. The rest are non-official experts from academia and non-Governmental research institutions. The WG also had the benefit of presentations and active participation of non-member officials and specialists in its discussions notably from IMD and CPCB.

The deliberations were structured around the following major themes: (1) agro-meteorological data and water resources potential from rainfall, surface and groundwater; (2) current utilization of water from different sources and for different uses; (3) impact on end uses; (4) major gaps in current data relating to the last two aspects and measures to fill them; and (5) broader issues of organization and structuring of a comprehensive and integrated National Water Resource Information.

On each of these the WG has reviewed the existing institutional arrangements, the extent to which data generated are adequate to meet the requirements of planning and policy, identified deficiencies and gaps (in terms of scope, coverage and reliability) and provided concrete suggestions to remedy them over the long run and specifically during the XII Plan.

2. Agro meteorological data

The source of all renewable water resources is it by way of natural recharge of soil moisture and groundwater or the volume of surface flows is rainfall. The volume of precipitation and its distribution over the year and the extent to which surface and groundwater are utilized for irrigation, taken together with other elements of climate (temperatures and sunshine) are critical determinants of the natural vegetation as well as the production of crop and non-crop biomass.

Data on rainfall and other aspects of climate are collected by observatories maintained and operated by IMD as well as the CWC, State Governments, and numerous non-Governmental organizations. Observatories have grown in number and the quality of instruments used has also improved. But these are not adequate to provide reliable and validated estimates, especially at the sub-district level, because of the inadequate density of the observatories, variable design of the instruments, and care with which observations are made and validated.

We have made some suggestions for studies to assess the correspondence of time series of rainfall in different regions based on IMD and non-IMD observatory data; and of the probable margin of errors in estimates of precipitation in high-rainfall upper catchments and the difference this can make to estimates of mean rainfall for the basin.

A major effort to expand and upgrade the network of observatories using up-to-date technologies is essential. In order to build an optimal network, we recommend that during the XII Plan the number of automatic telemetering rain gauges be increased from the present 10,000 to over 60,000 and also the installation of 60 Doppler Weather Radars. Such a system will drastically reduce problems in collection and transmission of rainfall data inherent in the current system. It is however important that this National network be built and operated as a cooperative effort between IMD and the States.

Besides rainfall, data on several other climatic variables (temperature, humidity, sunshine and radiation) are needed, though not on as large a scale as for rainfall. The number of climate stations equipped to collect these data needs to be increased taking into account the level of spatial detail required and the costs.

Techniques and methodology for estimation of potential evapotranspiration (PET) and soil moisture – critical parameters for preparation of water budgets for basins and projects, and estimating crop water requirements – need to be improved. IMD has lysimeters for direct measurement of Evapotranspiration (ET) at some 219 centers and the CWC at several reservoir sites. The number of centers with these devices needs to be expanded and their equipment modernized in a phased manner. Database on ET should include direct measurements from micro met towers of ISRO and CSIR.

IMD should continue to provide estimates of PET for different agro-climatic regions and sub-regions using empirical formulae. We recommend that in future the Penman method recommended by the FAO be used for this purpose, calibrated on the basis of systematic comparison of direct measurements in selected centers and formula-based estimates in the contiguous regions. The potential of satellite-based approaches for the estimation of ET also needs to be seriously explored.

3. Water resources potential

In the 1950's, A.N. Khosla, who headed the then newly constituted Central Water and Power Commission, used an empirical equation relating surface run-off to rainfall and evaporation (postulated as a function of temperature) to estimate average annual water resources potential in six regions. Subsequently, the CWC sought to assess the water resources potential in major basins. Studies based on statistical analysis of flow data wherever available and rainfall–run-off relations were done for 23 basins and sub-basins between 1952 and 1966, and for some major peninsular rivers and the Ganges and Brahmaputra basins during the 70s. At that time the needed data on rainfall, terminal discharge observations, and validated rainfall–surface flow relationships were limited.

In the early 90s, the conceptual framework for assessing water resources availability for several basins was refined on the basis of observed outflows at the terminal site for upstream extraction of surface water, reservoir evaporation and return flows, and taking explicit account of the contribution of groundwater recharge and interactions between surface and groundwater. For some large basins, estimates adopted by tribunals ((Narmada, Godavari, Mahanadi and Cauvery) and those based on special studies (Ganges and Brahmaputra) were used. Subsequent reviews by the NCIWRD and an internal group of the CWC followed the same procedures and more or less endorsed the 1993 estimates of the country's water potential. In any event, the estimates of overall water resources potential for the country made at different times have remained more or less the same.

The CWC is currently engaged in a joint project with NRSC to develop and test a water balance approach using remote sensing data for assessing overall water potential in two basins. It is also important to undertake rigorous analysis of rainfall–run-off relations in different regions using up-to-date data, ensuring that estimates of upstream extractions are based on reliable measurements, conducting systematic surveys to determine the magnitude of groundwater actually pumped, consumption for various non-agricultural uses, and other components of the balance equation. The problems involved and ways to address them are discussed in the report.

3.1. Utilizable resources

Estimates of overall water resources potential cover both surface flows and groundwater. Though these two sources are interrelated, estimates of their individual contributions, both overall and to utilizable volumes, are made independently by the CWC (for surface water) and the CGWB (for groundwater). Since interactions between these sources are significant, the sum of these two estimates cannot be taken as a measure of the total volume of available and utilizable water resources. It is essential that this exercise be done jointly by these two bodies.

3.2. Surface flows

The CWC estimates the potentially utilizable volume of surface water in the country at 690 BCM. This is the same as shown in the 1976 report of the National Agricultural Commission and in subsequent exercises undertaken by the CWC in 1988 and more recently in 2001. The estimates for most major basins made at different times have also remained more or less the same.

The WG was unable to locate any document explaining the basis for estimating utilizable flows. Reference was made to an early CWPC exercise based on a detailed study to identify potential storage sites and their capacities in all major river basins and their sub basins. These studies are no longer traceable. Nor do they find any mention either in the Irrigation Commission report or in any accessible CWC documents on water resources assessments.

The latest (2001) estimates of utilizable potential for major basins are reported to be based on the expected requirement for various end uses in 2025; estimated surface flow at 75% dependability, and in some cases tribunal awards. This exercise has also been done at the sub-basin level with a view to ensure equitable distribution of available water between regions where supplies exceed project requirements and those which face a deficit or are drought prone.

The limitations of these estimates have been highlighted in our report. Strong pressures for wider diffusion of irrigation in backward regions have led to a huge overhang of unapproved projects, enormous delays in completing the projects and realizing their design potential. It cites growing concerns about the current neglect of the role of rivers and river systems in maintaining a healthy environment, the social and environmental impact of large storages and of the controversial proposals for inter-basin transfers.

These concerns and the widely recognized fact that the country is facing an increasingly serious water crisis, underscore the importance and urgency of a rigorous and transparent review of the methodological and empirical basis for assessing utilizable potential of surface water and for techno-economic evaluation of projects in a professional and transparent manner to ensure equitable, sustainable and economical utilization of the available resources. We strongly recommend that the Planning Commission entrust these tasks to a group of knowledgeable and independent professionals with expertise and experience in water resources development in a broader and longer-term perspective.

3.3. Groundwater

The CGWB is the principal agency responsible for assessment of groundwater potential and its exploitation in the country, as well tracking trends in its utilization. It has done a considerable amount work to develop, test and refine the conceptual framework and estimation procedures for this purpose. It has assessed the volume of renewable groundwater resources generated by direct recharge from rainfall and indirectly on account of lateral seepage from rivers, streams, water bodies and canals.

These estimates are based on field studies of recharge rates under different agro-climatic and geological conditions. In addition, the CGWB (along with the State Boards) monitors the behaviour of water levels in over 50,000 observation wells across seasons and over the years. Studies on a more limited scale are being done on the estimation of several other aspects (delineating and mapping of aquifer disposition, specific yield, extraction rate, and groundwater quality) relevant for groundwater potential and use. Based on these data, estimates of groundwater potential and utilization as well as secular trends in water-table levels are estimated and mapped at the block level.

The report highlights the need for improvement in both methodology and empirical basis for several aspects of estimation of groundwater potential. It has made a number of detailed recommendations to address these deficiencies during the XII Plan as part of a phased long-term program. Following are the main areas that need attention. Details are spelt out in the report.

- Prepare a comprehensive plan for mapping the geometry, boundary and depth of aquifers, determined with an uncertainty less than 10%, using a conjunction of state-of-the-art geophysical technologies. Develop methodologies for micro-level mapping of aquifers under ongoing pilot projects and further downscaling of maps to 1:50,000 scale.

- Analyse existing data from sub-surface explorations, geophysical surveys and logging data available with different agencies and detailed information on well characteristics from the Minor Irrigation Census, to delineate major aquifer systems. Data gaps to be filled with various geophysical techniques to get continuous data of subsurface disposition.

- Obtain knowledge of the characteristic properties (flow and transport) of the aquifer, e.g. permeability/transmissivity, specific capacity, dispersion coefficient, storage coefficient using up-to-date methodologies covering the various geophysical, geo-hydrological and geo-morphological aspects.

- Periodic specific yield determination using multiple methods to be made at the level of assessment units.

- Monthly groundwater-level data at an optimally distributed network of ~100,000 monitoring wells in the country to be generated, of which 20% be equipped with digital water-level recorders (DWLRs).

- Use multiple methods to estimate rainfall–recharge relationship. Estimates to be made for all agro-climatologic zones and updated periodically (3–5 years). Periodical evaluation of the estimation methodologies and parameters necessary.

- Groundwater-level data along canals and around other storage structures together with the respective surface water-level data are needed for the determination of seepage factors.

- Assessment of groundwater draft requires comprehensive studies of spatio-temporal variability across various assessment units or even sub-basins.

- The CGWB and the State groundwater departments are to be strengthened with high-resolution water quality labs to serve as cross-verification and validation from other laboratories.

- It is necessary to explore ways to increase the capacity for such assessment at the micro-watershed community level. Both rigorous studies using up-to-date scientific techniques by academic institutions (like IISc) and efforts by NGOs to promote local institutions/groups involving Panchayati Raj Institutions, local urban/rural bodies for local-level planning and management should be encouraged in more locations on a selective basis.

4. Water utilization by source and use

4.1. Rainwater

Discussions of water resources availability and use focus mostly on surface flows and groundwater. Very little attention is given to the contribution of rainfall, which is the sole source of water for all uses in un-irrigated areas and a significant source even in irrigated areas. That more effective use of rainfall is necessary to increase water availability for domestic and agricultural uses in rainfed areas is widely recognized, and is in fact the rationale for the integrated watershed development program.

It is therefore important to know the extent to which local rainfall is effectively utilized, the potential for augmenting the proportion that can be harnessed for local use, and the efficacy of various programs being implemented for this purpose under different agro-climatic regimes.

Government and academic institutions as well as NGOs should be encouraged and supported to correct this lacuna by conducting properly planned and scientifically rigorous studies in selected watershed communities typical of different agro-climatic regimes. We strongly recommend that this must be taken up as a program of high priority during the XII Plan.

4.2. Surface water

The responsibility for the regular upkeep and proper maintenance of the various measurement and gauging systems for maintaining daily records of the measured volume of water released into their canal systems is left entirely to functionaries of the State Governments.

Functionaries responsible for managing all major and medium water resources project and CWC have done much to provide technical and financial assistance to set up instrumentation for the projects. The CWC regularly monitors the storage position of only major reservoirs, but not actual deliveries.

Arrangements to ensure observance of prescribed protocols of record-keeping and reporting are variable and on the whole quite lax. The States are reluctant to make the data available to the Centre, despite the fact that it is authorized in law to require the States to furnish the data and to check their accuracy.

The CWC is therefore unable to compile validated estimates of gross utilization from all major and medium projects on a regular basis. Such estimates are published for some years without details of their basis, coverage and accuracy.

The position in respect of minor works is much worse. Periodic censuses of minor irrigation works give some idea of their nature, size and spatial distribution, and of the area irrigated. But nothing is known about the volume of water supplied by them for various uses. They may account for a relatively small proportion of surface water use, but are the lifeline of hundreds of thousands of villages.

There is considerable concern about their deteriorating conditions and reported decline in area that they irrigate. Little is known about the impact of programs for their expansion and modernization in checking these trends. We have underscored the importance of undertaking special surveys periodically to monitor these aspects on a regular basis.

In order to expand the observation network at National Level, the Group recommends setting up of additional observation stations and strengthening of the existing CWC observation network to meet data gap as well as to prepare for climate change adaptation which require more intensive data both in terms of quantity and quality. The expansion of CWC hydrological network would invariably require restructuring of CWC. The Group is also of the view to strengthen the present WRIS being implemented by CWC. Based on the discussion in the Working Group meetings and the observations of the Group, CWC has prepared a detailed proposal which includes strengthening of Hydrological data network, Coastal management information system, NWRIC, Satellite based monitoring of reservoirs amounting to Re. 3850 crore. The details of the proposal are included at relevant section of the main report.

4.3. Groundwater

In the case of groundwater, the present method of estimating extraction is based on the number of wells/tube wells as reported in the Minor Irrigation Census and assumptions about unit draft. In the absence of any systematic survey, it is not clear whether they capture variations in the volume pumped per year per well across different types of wells in different regions. More so, because these characteristics are changing significantly and rapidly. Ideally we need reliable estimates of end use (disaggregated by industrial, agricultural and domestic uses) and their temporal variations at the level of assessment units.

For this purpose it is necessary to adopt a differentiated strategy to collect and validate the data for different kinds of wells across regions and those used for irrigation, domestic and commercial uses, and by different categories of industry. The only way to get reliable estimates of actual groundwater extraction is through sample surveys of all types of wells in rural and urban areas, distinguishing between wells which are primarily for irrigation as a sole source and used conjunctively with surface water, and those which are used primarily as a sources of domestic, commercial and non-agricultural uses.

The design and conduct of such a survey covering all regions is urgently needed both to assess the volume of water they supply and to assess the extent of lowering water table over time. We strongly recommend that this be undertaken during the XII Plan. Assessing trends over time requires that such surveys be repeated periodically.

4.4. Uses not covered by the above

Water supplied by canals is not used only within their designated command. Considerable volumes are used outside the command area. Pumping of flowing water in rivers and streams, and ground water from river beds is quite widespread. Much of this is unauthorized and therefore is likely to go unrecorded in the official statistics.

In order to assess their extent, we suggest a two-stage approached. (i) First identify locations of pumping sites along all major rivers and map the extent of irrigated area outside of but contiguous to major canal commands using satellite imagery. (ii)This is to be followed by a field survey of areas in a sample of identified locations to verify whether they are authorized, and assess the quantum of water extracted by them.

This is a challenging exercise for which we suggest that pilot studies of a few select rivers or river stretches be taken up in the XII Plan and extended later in the light of their experience.

4.5. Water consumption by end use

Estimates of current and projected water consumption suffer from even more serious limitations. These are not based on measurements of actual use, but on the assumption that estimated gross utilization from irrigation projects is used entirely in agriculture; and for non-agricultural uses on the basis of norms of desirable levels of consumption for domestic use and limited data on requirements per unit of output for industries and power.

Future requirements for agriculture are related to expansion of irrigated area required to meet targeted levels of output; requirements for domestic use are estimated by applying norms of per capita use to the projected growth of the population; those of industries and power presumably are linked to the projected growth in their outputs.

All these estimates relate to gross volume of water used by different sectors: effective consumptive use is much smaller and the balance, which forms a substantial part of gross use, returns to the hydrological cycle as wastewater or non-consumptive evaporation. Besides underscoring the importance of distinguishing between gross use and net consumptive use, we have suggested more direct ways to estimate these aspects.

Reliable region-wise estimates of consumptive use by crops can be made on the basis of area under different crops and seasons, crop patterns on irrigated and rain -fed lands and estimates of their respective evapotranspiration. We have recommended that this approach should be used to generate, on a continuing basis, seasonal and annual estimates of consumptive use in agriculture. Such studies should be initiated in the XII Plan using validated data on crop patterns and with appropriate refinements in the empirical formulae for estimating crop water requirements.

For other sectors, the only way to get reliable estimates of gross usage and the purposes for which they are used is through properly designed sample surveys of different categories of users (rural and urban households, commercial establishments, different industries and power generation). We recommend that the design and conduct of such surveys, on a scale that would generate reliable estimates at the State and National levels, should be taken up during the XII Plan.

5. Impact of irrigation on agriculture

5.1. Irrigated area and production

Irrigation impacts agricultural production by expanding irrigated area, raising cropping intensity, and increasing productivity of land through changes in crop patterns and higher yields per hectare of individual crops. Official statistics of land use and crop patterns is based on village-level records, and crop yields on the basis of sample surveys. Though comprehensive in coverage and level of crop and regional detail, the quality of data generated by this system (in terms of coverage, reliability and timelines) leaves much to be desired.

Efforts to restructure the arrangements for collection of land use and cropping statistics at the village level to make it more manageable have not been effective. Nor has the carefully designed scheme of sample surveys for estimating yields of major crops. There are considerable unexplained differences between the official estimates of land use and irrigated area at the State and National levels, and those generated by the National Sample Survey and the Planning Commission.

The deficiencies in the working of the existing system and the measures needed to address them have been reviewed recently by a committee constituted by the Department of Agriculture and Cooperation, Ministry of Agriculture. Implementation of their recommendations–which is currently in process – will provide reliable and objectively validated data on land use, cropping and yields and will become available in sufficient detail at the State and National levels. That would vastly improve the quality of data needed to assess the impact of irrigation in different dimensions at a macro level on a continuing basis.

This however needs to be supplemented by more detailed and in-depth surveys of both rainfed lands and areas irrigated by different kinds of projects – major and medium surface systems, minor surface works, and wells/tube wells. The purpose of these surveys is to provide comprehensive data on all important technical and operational aspects of water utilization and impact from different types of projects in different regions and river basins. These surveys, which would provide benchmarks to be tracked by repeating them at regular intervals in subsequent periods, should be launched during the XII Plan.

The systems to be surveyed, the scope and content of the surveys and their methodology should be decided by a Steering Committee comprising official and non-official experts in relevant disciplines under the auspices of the Planning commission.

Besides working out these details and formulating operational guidelines to be followed in the surveys of all selected locations, the identification of official agencies and non-Governmental research institutions for undertaking field work, the criteria for screening and selection among them and the MoUs laying out the terms and conditions of the contract with them, and the arrangements for supervision and inspection of field work should also be vested with the Steering Committee.

5.2. Water use efficiency

The above improvements would provide a better basis for assessing the impact of irrigation, overall and by the type of projects under different conditions of cropping intensity, crop patterns and yields. Alongside it is important to conduct studies to assess the water use efficiency in different regions under irrigated and rainfed conditions in terms of: (a) the proportion of total water applied that meets the consumptive use requirements of crops; and (b) overall crop production and of individual crops per unit of consumptive use.

We have cited studies, based on available data that seek to assess technical efficiency at the level of groups of major river basins and of productive efficiency in irrigated and rainfed areas at the level of agro-climatic regions. They leave much room for improvement using more detailed and reliable data now available along the suggested lines. Sustained research to improve the methodology and empirical basis for assessing water use efficiency is essential and should be actively encouraged and supported.

6. Implementation of recommendations

Successful implementation of the program requires active support from the highest levels of the Planning Commission and agencies responsible for water resources development.

Data improvement should be viewed as a National effort of the Centre and the States, with the Central Government taking the lead in working out protocols and procedures for collection and validation of data by all agencies, creating appropriate institutional arrangements to ensure independent and professional conduct of the surveys, providing financial and technical support to the States and ensuring that all agencies follow prescribed protocols and transmit the data to the central pool.

To handle these tasks in a coordinated way and with a broad perspective, we suggest the constitution of a Steering Committee chaired by the Deputy Chairperson of Planning Commission (or the member in charge of water resources) with senior professionals from Central and State agencies, and from academia and research institutions.

The suggested program for the XII Plan would, on an approximate estimate, require an outlay of Rs. 8050 crore (including Rs 3850 crore of CWC, Rs 1450 crore of CGWB, Rs 2250 crore of IMD and Rs 500 crore for surveys as well as in-house and sponsored research). The suggested outlay on data improvement amounts to barely 4% of this total plan outlay for the water sector. It is necessary to begin to make up for past neglect to build an adequate and reliable database and objective analysis of high professional standard for planning and policy.

The real challenge is not so much finance as in devising effective institutional arrangements and ensuring trained personnel to implement the programs. The following are the crucial tasks that need to be tackled:

6.1. Data collection for assessment of water potential and use

Central nodal agencies should articulate a common framework of scope, concepts and instrumentalities for collection and collation of data for assessing water resources potential and utilization from different sources and for different uses. They should also lay down procedures and protocols to be followed by all agencies and ensure that they are in fact observed by these agencies, including non-Governmental agencies. Concerned official agencies and non-official experts should work in collaboration to evolve a coherent overall framework mindful of the complex interrelations between different aspects.

Compliance by the States, which will continue to collect much of the primary data, is particularly important. Their reluctance to ensure strict observance of protocols and provide complete and validated data to the central pool has been a problem. The Centre must persuade them about the importance of their cooperation in this respect. Besides incentivizing them to do so (by funding the cost of installing and operating upgraded physical infrastructure and training of personnel), the Centre must assert its authority under existing law to require the States to provide the data specified by it and to verify their validity.

The proposed program requires significant up-gradation of skills of the existing staff of both Centre and the State at the ground level. Ensuring adequate number of trained staff is the other important requirement. Effective use of more sophisticated instrumentation on the scale proposed in the report calls for a significant increase in the number of staff with higher order of training and skills than is currently available, and facilities for its proper maintenance and repair. Central nodal agencies must make an in-depth review of the requirements and work out an operational plan to meet them.

6.2. Sample surveys

Available data for assessing trends in land use, crop patterns and crop yields are quite inadequate in terms of both coverage and reliability. Restructuring of the existing system for generating these data is in urgent need of a thorough reform. We have endorsed the recommendations of the expert committee for improvement of agricultural statistics for such a restructuring to get objective and validated estimates at the State and National levels.

In addition, we have suggested sample surveys to provide: (a) comprehensive data on all important technical and operational aspects of water utilization by source and for different uses and their socio-economic impact of different types of projects, and (b) reliable estimates of consumption of water for non-agricultural purposes in different regions and river basins. These are meant to provide a benchmark of the current situation, against which changes over time are to be tracked through periodic resurveys of the same projects and locations.

The actual surveys will have to entrust to the Government and non-Governmental research institutions with interest and experience in such studies. It is important to have an institutional arrangement for the proper conduct of these surveys through a network of research institutions using well-defined common concepts and methodologies to ensure comparability across regions and over time. In order to track trends over time, the surveys of selected projects/regions should be repeated periodically.

They should be planned as a National effort with the Central Government taking the lead in providing adequate and assured funding for these surveys and creating appropriate institutional arrangements to ensure independent and professional conduct of these surveys.

We suggest the constitution of a high-power Steering Committee in the Planning Commission to work out the modalities of organization and funding of the program, deciding the criteria for screening and selection of institutions for conduct of the surveys, MoUs laying out the terms and conditions of the contract with them, and the arrangements for supervision and inspection of field work.

The scope, objectives, design and field procedures and validation must be the same for all basins and regions for each survey theme to be worked out by specialist sub-groups and Steering Committees set up by official and non-official experts in relevant disciplines.

We recommend adoption of the structure and processes evolved by the National Family Health Survey as being appropriate for the survey program, and one which would help create and nurture an interactive and collaborative research network for sustained research on water-related issues.

6.3. Research

Our recommendations, if implemented, would generate far more data of wider scope, greater reliability and detail than are currently available for assessing water resources, their use and impact; tracking trends in the use of water from different sources and for different purposes and policy, program and project planning at different levels based on rigorous and objective analyses. But in order to exploit this potential it is necessary to strengthen interest in, and in-house capability for, such analysis as the basis for decision making in Government agencies at both the Central and State level.

Equally important, Government agencies must do a lot more to encourage both Government and non-Governmental research institutions and scholars to use the data for research on specific issues and operational problems of current concern and longer-term strategic issues of more basic scientific interest. This can be, and needs to be, done in several ways.

1. Commission experts from research institutions as consultants to provide analysis and advice on technical aspects relating to the design of particular projects or problems relating to particular regions.

2. Sponsor similar research projects but of broader scope and focusing on a class of problems of interest to each agency.

3. In select areas that call for a multi-disciplinary approach, undertake collaborative projects with other Government agencies and with participation from invited outside experts.

4. Prepare a program of research on selected themes, invite proposals from interested researchers/institutions, and select projects to be funded based on an independent review process.

5. Give liberal access to all available data on all aspects to interested researchers, leaving them free to explore themes/issues of their interest.

Our report has indicated numerous issues on which rigorous and sustained research is needed.

In order to facilitate research it is important to ensure that all primary data collected by field agencies of all departments be digitized and transmitted to a pool at the State and National levels. Collations at the higher levels have to be selective and less detailed in terms spatial and time coverage. But they should form part of an integrated and interlinked system which permits details to be accessed at all levels. While individual agencies may have their own computerized data networks, the creation of such a platform is therefore essential.

The current program of the WRIS unit of the CWC is not equipped to handle this task. Its scope is limited. Even within the areas it seeks to cover, the coverage, reliability and details of data being collected are inadequate, and there are difficulties in getting other agencies (including especially the states) to report all the data they collect. We strongly recommend the proposal to set up a special, professionally managed and autonomous National Water Resources Information Centre. The organization has to be much larger, staffed by trained professionals specialized in relevant fields, and become a continuing activity.

The expansion in scope and detail of the platform, training programs and in-house research needs to be prioritized in terms of importance and feasibility. We suggest the constitution of a National Advisory Committee on Water Data Base, comprising experts in the design of digitized databases, professionals from the data-generating and using agencies within the Government, and experts from academic and research institutions to recommend (a) the scope and content of the data to be included; (b) technical aspects an appropriate design of the website; (c) the scale and composition of the staff in terms of professional qualification and training; (d) the organizational and managerial structure of the organization, and (e) a program for training of professional manpower and arrangements for implementing it based on a prioritized and phased expansion of the scale and scope its activities. It needs, however, to be planned carefully and implemented in a phased manner as the new data system begins to deliver and the staffs with professional skills in designing and managing a large and sophisticated system are trained. Besides professionals from agencies generating the data, it is important to involve outside experts knowledgeable about interconnections between different aspects of water resources in the design and management of the platform.

REPORT

1. INTRODUCTION

Water plays a crucial role as a basic, life-sustaining resource, as a source of irrigation and non-agricultural uses. The exploitation of this renewable but finite resource has increased manifold to meet the demands of the growing population and an expanding economy. Increasingly intensive competition (and the resultant social and political tensions) between uses and users for available supplies, and falling groundwater tables are unmistakable indications that demand for water is outstripping its availability. Water has thus become an important and highly contentious issue of public policy. It is therefore essential to work out rational strategies and policies for coping with the situation and encourage informed public discussion of alternatives to arrive at an acceptable social consensus on how best to balance competing claims.

Rational and sustainable water management has become a far more complex and difficult task (technically, socially and politically) than can be handled by traditional cost–benefit analysis of particular projects. It calls for reliable information on a wider range of aspects and comprehensive knowledge regarding the current and emerging situation regarding sources and uses of water; the scope for and ways of augmenting supplies and increasing the efficiency of water use; alternative possibilities available, their technical feasibility and implications both beneficial and adverse (including displacement, forest submergence, impact on riverine and estuarine ecosystems as well as sustainability) and associated costs, and the distribution of costs and benefits between regions and 'stakeholders'.

The current state of information and knowledge about water resources in India is widely known to be inadequate in scope and coverage:

- Collection of data is fragmented between different agencies. The agencies responsible for collection of the 'physical data' (to use precipitation and stream gauging as examples) are administered by differing Ministries, while the user data come under such diverse classifications as public health and sanitation, irrigation and urban planning. There is a consequential absence of a coherent and internally consistent conceptual framework and protocols for data collection and validation.

- The fact that 'water' is a 'State' subject leaves the Union (Central) Governmental agencies that are responsible for the National data with little choice but to rely on the State agencies for such data. Agencies of the Central Government – India Meteorological Department (IMD), Central Water Commission (CWC), Central Ground Water Board (CGWB), Central Pollution Control Board (CPCB) – do collect a considerable amount of data, but most of the information at the regional and project levels is collected by the State agencies. As a result, much of the data are not readily accessible even within and between Government agencies concerned with water resources development, leave aside in the public domain.

- The Hydrology Project that has now completed its first phase has expanded the physical infrastructure and equipped it with improved measuring and recording devices. The idea was to collate them into a National data network (called HIS) to facilitate easier access to users. But accomplishments have fallen far short of expectations because of the reluctance of the States to send all the information they collect fully and promptly to the National data pool.

These problems have long been known to the concerned Government departments that collect and are custodians of data as well as to the data users. But it is only now, as part of the preparation for the XII Plan, that the Planning Commission decided to constitute, for the first time, an expert group to address the present system for collection and dissemination of water related data and to suggest improvements. The Terms of Reference of the WG as stated in the constitution order of the Planning Commission are very wide. The WG is expected to:

- Spell out the database requirements for rigorous documentation and modeling of water resources available in the basin – their volume, quantity, connectivity and variability across seasons; and the status of use and users of these water resources, including their socio-economic status. Suggest modalities of achieving these requirements.

- Spell out the database requirements for the determination of environmentally sustainable limits on surface and groundwater that may be withdrawn from the water resources of river basins so as to determine maximum long-term annual average volumes of water that can be sustainably drawn from each basin, clearly delineating the requirements of drinking water and the environment. Suggest the modalities of achieving these requirements.

- Review the current methodology of assessment of groundwater resources and suggest changes if required.

- Suggest a mechanism for comprehensive aquifer mapping at an appropriate scale in line with the location of the aquifer, which includes aquifer type, water level, water quality, water use and profile of water users. In each case also spell out:

  - ✓ Personnel requirements.
  - ✓ Capacity-building needs.
  - ✓ Possibilities of participatory monitoring with involvement of local communities.
  - ✓ Possible use of remote sensing to build database systems and modeling.
  - ✓ Ways of achieving inter-departmental coordination and data harmonization.
  - ✓ Costs of the exercise.

- Suggest creative ways of presenting information in accessible forms to facilitate informed decision-making by the communities.

- Suggest ways of using simple IT tools and remote sensing to demystify information and make it accessible.

- Institutional back-up for data collection, database management and monitoring.
  - ✓ List existing institutions and their respective roles.
  - ✓ Assess the need for new institutions to meet the required roles.

- Any other issues considered relevant by the WG.

The list of members of the WG is given in Annexure 1.The 17-member Working Group (WG) consists of eight senior officials from the CWC, CGWB, NIC, WRD Government of Maharashtra and principal Government research organizations dealing with water-related issues. The rest were non-official experts from academia and non-Governmental research institutions. The WG also had the benefit of presentations and active participation of non-member officials and specialists in the discussions notably from IMD and CPCB. (A list of non-members who contributed to our deliberations is given in Annexure 2).

1.1. Procedures adopted by the Working group

The WG held six one-day meetings in the premises of the CWC in Delhi beginning December 2010 (see Annexure 3 for dates and venues of these meetings). At its first meeting, the WG had the benefit of a background note describing the main features of the institutional framework and facilities for collection of hydrological data, the desirable level of facilities, and the plans for achieving them (Annexure 4). There was an extensive discussion on the main issues to be examined with the objective of crystallizing the agenda for focused discussions. Subsequent meetings had the benefit of presentations on different kinds of data, the adequacy of current arrangements for collecting them, and ongoing and planned improvements. (A list of presentations made to the WG is given in Annexure 5). This was followed by detailed and frank exchange of ideas and views on the deficiencies of the current system and proposed plans, and on the strategy to address them.

The deliberations were structured around the following major themes: (1) India's water budget, agro-meteorological data and water resources potential from rainfall, surface and groundwater; (2) estimates of current utilization of water from different sources and for different uses; (3) Impact on end uses; (4) scientifically designed investigations to fill major gaps in current data relating to the last two aspects, and (5) broader issues of organization and structuring of a seamless, comprehensive platform for a National Water Resources Information Center (NWRIC). The remainder of the report is organized accordingly.

2. AGRO-METEOROLOGICAL DATA

2.1. Requirements

The source of all renewable water resources is rainfall. The total freshwater annually available to a region is equal to the sum of the average precipitation in different spells. This finite resource is, in part, returned to the atmosphere through evapotranspiration from natural and cultivated vegetation and from the surface of uncultivated land. The remainder is partitioned between surface flow in streams and rivers, and infiltration to recharge groundwater.

The volume of precipitation and its distribution over the year, together with other elements of climate (temperature and sunshine) are critical determinants of the nature of vegetation as well as the volume of biomass produced under rainfed conditions. Although limited to the Himalyan Rivers, contribution from snow melt is an important component and needs monitoring in light of its postulated increase over the years. Evapotranspiration provides the basis for estimating consumptive use of water by crops. Groundwater recharge is also a function of the annual regional precipitation and the characteristics of its land and sub-surface geology. All these features are variable across regions and over time. Reliable, detailed and spatially disaggregated data on rainfall in all these dimensions are therefore important for several purposes.

- **Progressively refined water resources assessment for management: conservation and development:**

  Accurate estimates of available and utilizable water resources in the country as a whole as well as in its widely diverse regions constitute critical numbers for its rational management. As total water use in the country begins to approach the total utilizable resources available, the requirement of accuracy in estimates becomes proportionately more stringent. It would, therefore, be prudent to design our rainfall data acquisition system over the entire country to be such as to allow high-resolution analytical frameworks to be brought to bear on water management at various space–time scales. Additionally, appropriate measuring systems would need to be devised and installed to quantify important losses such as those by evapotranspiration and transboundary flows as well as contributions from snow melt.

- **Weather advisories for the onset and progress of monsoons and number of rainy days; extreme weather events**

  This service is currently provided by IMD at the National level and also by a few State agencies to empower farmers and managers of the irrigation and power departments with advance anticipations to optimize the timetable of their operations: sowing, controlled release of water from reservoirs, flood mitigation measures, etc. As our designed world becomes increasingly dependent on centralized supplies, the role of advisories and, especially of their reliability, becomes critical in mitigating the impacts of shortages as well as sudden deluges. In particular, the resolution, lead time and accuracy of the forecasts have to be designed, if not immediately achieved, keeping the current and projected needs.

- **Assessment of the contribution of rainfall to soil moisture and its relation to land use, cropping patterns and yields in un-irrigated and irrigated tracts under different agro-climatic conditions**

  Rainfall is widely used for short term crop forecasts but there is considerable room for improvement both in their methodology and empirical basis. A better understanding of these relationships in both rainfed and irrigated tracts, and their behaviour over time is important to assess the potential for augmenting and making more effective use of rainfall in rainfed tracts and more efficient use of irrigation water.

- **Rainfall–groundwater recharge functions of aquifers in different agro-climatic regions, and trend analysis**

  One of the poorly understood factors is the proportion of rainfall that seeps into the ground, thereby making it difficult to reliably assess the groundwater resources which are replenished by annual rain. However, scientific analysis can enable determination of this factor in different regions, if adequate data from co-located rain gauge stations and well-water levels are available. This requirement, in turn, imposes a condition on the geographical distribution of rain gauges. Water levels in wells are currently measured at ~40,000 sites in the country, or on the average roughly about one per 80 km^2. Thus, an expansion of rain gauge density to an equal scale (about 30,000) would not only enable a better assessment of groundwater resources replenished by rain, but would also add greater reliability to the activities stated above.

- **Systems design for optimized water management: conservation and development**

  Water being a basic yet finite resource, the call for its ever more efficient management and design is going to become strident sooner rather than later, requiring innovative complexes incorporating conjunctive use of surface and groundwater, treatment and recycling, waste minimization and desalination in coastal areas. Creation, regulation and maintenance of such complex networks would, in turn, require rapid-response 'Artificial Intelligence and Expert Systems', which make exacting demands on various data elements such as high frequency accurate rainfall data amongst others.

- **Future planning**

  Since the annual average rainfall sets a limit to the total water availability and its fractional utilizability, this knowledge constitutes the starting point for future planning. Additionally, because of large regional variability, a more detailed knowledge about its geographical and temporal variability is required for exploring future possibilities. Finally, it will soon be found necessary to recreate the climatology with advanced analysis/debiasing algorithm and assimilation of information from augmented observation systems.

- **Compatibility with progressively refined models: new scientific insights, processes, assessment, management and design**

  Computer simulation models are becoming increasingly more evocative of the complex dynamic regime of the water cycle, but these are equally demanding of the data density, both spatially and at short intervals. Keeping in mind future developments in modeling and simulation, and the imperatives of using these as aids to ever finer management protocols, the prudence of designing future observation networks that would be compatible with the dense data requirements of models, can hardly be overemphasized.

2.2. Currently generated data and gaps

Data on rainfall, evapotranspiration and soil moisture, and other aspects of climate are collected by observatories maintained and operated by IMD. Rainfall data are also collected by the CWC, State Governments and numerous non-Governmental organizations, which together maintain some 8500 rain gauges (see Annexure 6 for details of the current observation networks of IMD). These are however of highly variable quality in terms of both the equipment used and the cares with which measurements are made and recorded. The majority do not report the data to IMD. The present status of the sources and coverage, of these data is shown in Table 1.

Table 1: Present status of data generation

Sl. No.	Items	Status
1	Rain gauges: rainfall data are archived at the National Data Centre (NDC), IMD, Pune.	• 559 rain gauges maintained as a part of the IMD observatories and 3540 rain gauges maintained by other organizations report data to the NDC. 5039 rain gauges maintained by other organizations do not report their data to NDC. • There are numerous other privately managed weather stations being maintained that need to be brought under the purview of these data. A significant number is under the control of C-WET (for example). • IMD proposes to install 3350 ARGs and 950 AWSs for hourly data by the end of the XII Plan.
	Doppler Weather Radars (DWRs)	11 DWRs have already been procured by IMD, and are currently being tested and calibrated. 55 DWRs are proposed to be installed by the end of the XII Plan.
	Potential evapotranspiration (PET)	Evapotranspiration in plant environment is measured using 42 lysimeters – 9 volumetric and 33 gravimetric. Evaporation is measured by means of US Class A Pan Evaporimeter at 219 locations.
	Soil moisture.	Soil moisture is measured weekly at 43 stations at depths of 7.5, 15, 30, 45 and 60 cm to calculate volumetric soil moisture and produce advisories for crop scheduling.
	Snow melt	Snow-melt contributions to the Himalayan rivers are significant. At present, there is little or no direct measurement of this component, barring few monitoring stations being maintained by institutions such as WIHG, SARI, etc.
2	Derived data: Dates of the onset and withdrawal of the SW monsoon are derived from the long-term Pentad mean rainfall data	An example in the Annexure 6 shows the long time trend of the monsoon onset.
	Number of rainy days	Rainy days, marked by rainfall greater or equal to 2.5mm over a 24 hour - day, are recorded for the study of spatial and temporal patterns of annual normal rainy days and their changing trends (NCC Research Report).
	Extreme weather events	Stations with significant increasing/decreasing trend in one-day extreme rainfall at (a) 95% significant level and (b) 99% significant level are recorded using Mann–Kendall non-parametric trend test.
	Evaporation maps	Weekly PET and climatic soil water balance are estimated for 144 locations in the country. These are used to prepare monthly and annual evaporation maps showing areas of daily mean monthly and annual evaporation based on mean daily evaporation data for 176 stations. IMD also provides empirical estimates of PET (monthly and in some cases weekly) in a normal year for 128 agro climatic regions of the country based on Thornthwait equations of the relation between PET and select climate variables.

3	Hydromet services and related research investigations	Hydrological service: Based on real-time daily rainfall data, weekly district-wise, subdivision-wise and State-wise/season-wise rainfall distribution summaries are prepared in the form of rainfall tables and maps. District-wise and subdivision-wise rainfall statistics provides important information useful to the agricultural scientists, planners and decision-makers. The inputs on rainfall are provided to the CWC through the ten FMOs established in different parts of India for operation Flood Forecasting. These include QPFs issued by the FMOs and supplied to the CWC for flood forecasting purposes. Design storm studies were conducted to evaluate design storm estimates (rainfall magnitude and time distribution) for various river catchments/projects in the country, for use as main input for by design engineers in estimating design flood for hydraulic structures, irrigation projects, dams, etc. on various rivers. During the current year, 49 projects have been completed and the results communicated to the concerned project authorities. Isopluvial (return period) maps of rainfall for all the States have been published. Hydrometeorology of the Yamuna Basin has been published and is in progress for other basins.

2.3. Some issues relating to currently available data and on-going programs

IMD uses data from 2500 observatories to estimate daily, weekly and average rainfall during the year. These estimates are made and published for each of the 36 meteorological divisions. Past data on all these details are available in the IMD archives in a digitized form.

IMD also estimates ‘normal’ rainfall using observations from both its observatories and 7500 others maintained by the State Governments and non-Governmental agencies. Normal rainfall is the average of observations over a 50-year period revised every ten years. For a given area (territorial, natural region or watershed), it is the simple average of data from all observatories in that region. Estimates for larger regions are reported to be weighted averages of estimates for components of smaller units. Though the density and quality of rainfall stations vary, the data are pooled across agencies and their simple average is used in the estimates.

The WG observed that the distribution of the observation points for the rainfall data fails to capture the geographic distribution, since there is a lopsided concentration of the observatories in the plains, while those in the upper catchment areas of the basins are sparse. As a result the actual catchment contribution to the water resources (both surface and groundwater) tends to have a bias from the lower reaches. The density of observatories in the high-rainfall upper catchment of rivers is admittedly inadequate, but measures are reported to be underway to increase it by setting up more observatories.

It was suggested that studies for sensitivity analysis of data be initiated in selected basins to assess the extent to which the estimates of total rainfall in the basin would be affected under different assumptions about the margin of error in the estimates for high-rainfall segments. Furthermore, rain gauges to be selected for installation at all future sites should be of the telemetered type (TRGs) to facilitate near real-time analysis as well as a regular check on their health. The issue regarding the quality of the sensors required for the tropics (e.g. 2-bucket vs. 4-bucket), too must be sorted out on scientific grounds.

It also needs to be clearly recognized that Doppler Weather Radars (DWRs) do not directly give rain figures on the ground, and therefore require careful calibration. These would ideally require ground-truth availability with a density of at least one every 50 km^2, which needs to be built into future programs in order to gain the best dividends from the high investments in DWRs.

The design and equipment of rainfall observing stations maintained by non-IMD agencies and the quality of data recording by them are changing over time. IMD observatories themselves are being rapidly upgraded into Telemetered Automatic Rain Gauges (TRG) and Automatic Weather Stations (AWS). Despite this, the estimates of total normal precipitation in most basins have remained more or less the same over the last 70 years. Here again it might be useful to compare estimates of levels and trajectories of average rainfall at different points in selected regions (say districts/sub-basins/met subdivisions) based on data from IMD stations with those based on non-IMD stations.

Rain gauge stations are currently being operated both by IMD as well as several State and research organizations, and the share of the latter is bound to become much larger with new demands on real-time and semi real-time data for specific purposes. However, there is, and would remain an overwhelming case for making all datasets, irrespective of the agency collecting them, to be internally consistent. This basic requirement was visualized as far back as 1890, when the Government of India adopted a rainfall resolution (vide Annexure 7), valid even today, declaring IMD to be the custodian of all rainfall data-generated in the country, and requiring all rainfall data-generating agencies in the country to demonstrably adopt the standard practices of installation, recording, dissemination and compilation of rainfall data as stipulated by the 'standard practices' documented by BIS in coordination with IMD.

This highly desirable protocol needs to be firmly rooted in the rainfall data-generating installations and practices that should be binding on all agencies involved in this task, with the fiat that IMD reviews its earlier formulation of 'standard practices' in view of the many constraints now confronted by scientific installations, and also rigorously inspects its own current installations some of which are clearly seen to violate its own prescriptions.

2.4. Evapotranspiration (ET) data status

ET constitutes an objective basis for estimating the consumptive water requirements of crops. It also provides an objective basis to assess the adequacy of available supply for optimum crop growth. It is, however, inadequate for estimating evaporation from forests and areas with dense tree cover.

IMD has published estimates of ET in a normal year, State wise and for various agro-climatic regions and sub-regions using empirical relationships (Thornthwait formula) between climatic variables and evaporation. These are based on data from centres equipped to measure relevant variables, viz. temperature, sunshine, precipitation, and wind velocity.

Despite widespread application of the ET concept, there has been considerable ambiguity in the use of terms such as potential ET and reference crop ET. To overcome this, the Food and Agricultural Organization (FAO) of the United Nations brought out a report, commonly referred to as FAO-56. This report has introduced uniformity and standardization in the interpretation and use of various terms such as potential ET and reference crop ET. FAO-56 discourages the use of the term potential ET because of ambiguities in its definition. FAO recommended that a hypothetical reference surface 'closely resembling an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water' be adopted as the reference surface.

The ET rate from a reference surface, not short of water, is called the reference crop ET or reference evapotranspiration (RET) and is denoted as ET_0. The reference surface is a hypothetical grass reference crop with specific characteristics. To estimate ET from a well-watered agricultural crop, FAO has recommended the use of the modified form of the Penman equation, widely known as the Penman–Monteith (PM) equation.

ET data are an important input in the preparation of water budgets at basin, sub-basin and project levels. These are also useful for the preparation of internally consistent planning of cropping intensity and crop patterns as well as distribution and scheduling of water deliveries in irrigation projects consistent with given available supplies. However, at present these aspects are based on assumed gross duties (usually hectares per unit volume of gross supplies) rather than ET and explicit assumptions on the efficiency of delivery. Despite its importance, the present availability of ET data for the country is grossly inadequate.

The WG recommends that IMD adopts the FAO-56 PM method[1] to estimate RET and publish the data (preferably at daily timescales) and maps of RET annually for at least each agro-climate region and at a finer resolution, if possible. IMD has some 42 centers equipped with lysimeters and 219 pan evaporation center for direct weekly measurement of actual evaporation on a continuing basis. The CWC/reservoir-operating authorities estimate evaporation from reservoirs using the data of pan evaporimeters and the reservoir water surface area; the estimates have not been collated and published. A comparison of its overall and seasonal magnitude obtained from direct measurements using lysimeters and other equipment from IMD and CWC centres with corresponding empirical, formula-based estimates in contiguous locations would help determine the reliability of the latter. Whether the ET rates are changing over time because of changes in climate and land use will also be clarified by time series analysis of data from IMD stations.

Direct measurement of ET by the eddy covariance is being attempted in many countries. Recently, in India such towers are being established by CSIR and ISRO. Under CSIR, 20 towers (termed as meteorological profilers for climate observation and modeling) have been set up across India and are in operation. Similarly, ISRO has installed 20 micromet towers across various locations in India, which are in operation. It is high time that several more such towers are established across India for a better assessment of actual ET. The satellite-based approaches for estimating ET are gaining interest in several parts of the world. Using satellite products it is feasible to estimate ET at scales of a few square kilometer. Hence establishing a good ground network of observations will facilitate the calibration and validation of satellite estimates.

---

[1] FAO, Crop evapotranspiration, by Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., Irrigation and Drainage Paper No. 56, Food and Agriculture Organization, Rome, Italy, 1998.

2.5. Soil moisture data status

Soil moisture data are critical inputs in crop water management and hydrological modelling but the present network of stations equipped to measure such data is very thin. Data may exist with agronomical stations and in agricultural universities, but these are not pooled centrally at the moment. It is necessary to significantly increase the density of such stations. Resources of agricultural universities and their extension centres may be pooled with IMD to create and operate a dense network of soil moisture data.

Satellite-based surface soil moisture approaches are gaining interest across the world due to the availability of microwave satellites, which can estimate soil moisture even under cloudy sky and have finer spatial resolution. A good temporal frequency is also possible due to the availability of multiple satellites (ENVISAT, RADARSAT-2, ALOS). India will be soon launching RiSAT, a microwave satellite that can estimate soil moisture at a very high spatial resolution of 20mx20m. Recently, SMOS was launched by the European Space Agency, which has the capability of estimating surface soil moisture every three days with a coarser resolution. There is an urgent need to calibrate these satellite products in various sites of India to establish the relationships between surface soil moisture and the variables measured by these satellites so as to utilize the satellite products for operational use in agriculture and water resources applications. Hence establishing a network of ground stations for estimating surface soil moisture at various sites in India will be required.

2.6. Programs for strengthening observation networks

The requirements of rainfall and related climate data for tracking and interpreting agricultural developments, better planning of water resources development and for meeting the challenges posed by the environment and climate change call for data of scope, quality and detail. Advances in scientific understanding, estimation methodologies and computer simulation schemes make this possible. But we need to recognize that the needs are far larger than is feasible within the constraints set by available resources of organization, personnel and finance. It is therefore necessary to have a phased and prioritized program to meet the numerous and growing requirements.

The WG noted that IMD is expanding the number of stations and upgrading their technology. The aim is to ensure that, eventually, there are at least three stations per district. Given the high regional variability in levels and trends of rainfall, IMD has a plan to increase the number of rainfall-observing stations and reach up to the Taluk level. In expanding network coverage, the data requirements for evaluating the effect of climate change will also be taken into account.

The contents of requisite data, the level of detail and the periodicity needed for various purposes are not uniform: For example, whilst water resources development may require only monthly/fortnightly/weekly data, flood forecasting and management require short duration (~6 – 24 hours) rainfall data and urban flood/flash flood warnings require even shorter interval data, at intervals of 15 minutes or less. Hydrological designs, on the other hand, require extreme rainfall or probabilistic rainfall data, and climate change studies require trend analysis of long-term records to make reliable projections that would not be present in the past records.

These requirements can be better met with a system for collecting basic data that meet the above criteria provided, of course, that the primary data are accessible for processing and analysis for specific uses and users. The number of observation points as well as the scope and scale of observations should be expanded in a phased manner depending on the growth of demand for data on more aspects and in greater detail, keeping in view their justification in terms of benefits relative to the cost of such expansion.

2.7. Recommendations for the XII Plan

Keeping these considerations in view, we recommend the following program for the XII Plan:

2.7.1. Rainfall and climate data network

The impending water crisis, and the analytical and visualization possibilities that would enable its stringent management, call for a rainfall data observation system, which would be a real-time, standardized monitoring network geared to an automated data archiving and retrieval system which will be free from human errors. Modern technology makes it possible to achieve this goal through a hybrid system of DWRs which have a perception radius of about 200 km, supplemented with an adequate number of TRGs required for calibration, ideally one per 50 km^2 to enable reliable estimations of: (i) the various components of total water budget of the country, and (ii) a range of regional hydrological cycle process factors required for knowledge based optimization of water management designs**.**

Ideally, a reliable set of real-time precipitation data covering the entire country (3.28 million km^2) can be generated in a standardized manner free from human failure, through an optimal network of ~ 60 DWRs with a radius of perception equal to ~200km, provided they are meticulously supported and calibrated by ~40,000 automatic telemetering rain gauges. Their standardized formats and calibrations would also enable countrywide consistent rainfall data and their user friendly retrieval and dissemination to bonafide users.

The proposed network of 40,000 ARGs can be accomplished by setting up an additional 30,000 of them during the next Plan period through a cooperative effort between IMD and the States. An example of such a network is already envisaged in Karnataka. It is being further augmented to contain 5000 stations. This will give an opportunity to upgrade the State-level observation networks to the same standard as the National network and help vastly improve the quality and coverage of data.

To incentivize the process, we suggest that the Centre should finance the capital and operating cost of upgrading State networks and arrange for the training of personnel with professional skills to operate them, subject to the condition that they (the States) should observe the protocols prescribed by IMD, be open to inspection by its officials and undertake to transmit all the data to the National database. Additionally, a serious and methodical effort to bring all non-Governmental (non-IMD) AWSs/met stations under the umbrella of a system that allows data standardization as well as integration into the National dataset is required.

2.7.2. Evapotranspiration and soil moisture

The current evapotranspiration and soil moisture measurement network is highly inadequate. Estimates based on direct observation derived in the past are most likely invalid now because of the considerable change in land-use patterns and meteorological conditions. As extant lysimeters have become very old, an adequate set of lysimeters equipped with digital/load cells, and data logger and GPRS transmission facility needs to be installed, and data collected and analysed to enhance the reliability of agro-met advisories on irrigation scheduling. The density required to get sufficiently disaggregated estimates for different agro-climatic regions, and to provide information for management of water in major projects and phased programs covering design and costs, to achieve optimum density over the next 10 years needs to be worked out. Here again, a conscious effort must be made to build National network in collaboration with the States, with financial support conditional on their being supervised by IMD.

We further suggest that direct measurements of PET in the 219 centres should be compared with empirical estimates in contiguous centres to establish the degree of confidence with which the latter can be used for operational purposes. If this exercise establishes the empirical formulae to be reasonably accurate, empirical methods can be used to get PET estimates for a much larger number of centres which are equipped to provide data on the relevant climatic variables.

2.7.3. Soil moisture

There are protocols by which estimates of daily PET estimates taken together with precipitation data can be converted to assess the soil moisture conditions in different seasons. Attempts have been made under the National Water Mission Project to use remote sensing to get real time data on soil moisture status in different segments of the command for flexible adaptation of scheduling to maintain optimum soil moisture conditions. But the results of these studies and their usefulness for improving water deliveries have not been assessed. Also, this approach has not been sustained.

Soil moisture status can also be estimated through remote sensing techniques, which needs to be corroborated/ validated through actual measured ground data. In a similar pattern of gridded rainfall data, PET data should also be made available on $1^{\circ} \times 1^{\circ}$ grid. This would greatly enhance the value of these datasets for assessing crop prospects in each season.

These estimates need to be validated by actual measurements on the ground in agricultural research stations that have experimental plots which are monitored by scientists, who have the necessary equipment with which to make the needed measurements.

The efforts undertaken by various agricultural universities and the agro-met divisions of the State remote sensing applications centres (including the NRSC Agro-met Division) in terms of soil moisture monitoring need to be made inclusive and not limited to the ‘research’ domain.

2.7.4. Hydrometeorology

Three important phases of the hydrologic cycle are: (a) precipitation (b) Evaporation and evapotranspiration and (c) percolation and runoff. The first two of these are meteorologically controlled and are therefore considered the domain of Hydrometeorology. The remaining two provide estimates of usable water resources. The predominant objective of hydrometeorology is quantified estimation of rainfall and evapotranspiration for specified domains viz. river basins of the country and agricultural plains.

The foremost consideration is that of monitoring hydro-meteorological variables. On an event basis the quantum of rainfall is highly variable in space and time. The spatial variability reduces as we average out over a period of time. Thus for different purposes the ideal density of observing network varies. To assess agricultural needs of soil moisture a monthly average is suitable and the corresponding linear density is of the order of a 100 km or so. On the other hand when estimating run off is the objective every event counts and the linear density should be 5-10 km. At the same time evaporation and evapotranspiration are less variable than the rainfall itself thereby necessitating a linear density of 50 km or so.

A second consideration is that of predicting the variables for the domains mentioned above. Weather forecast models aided by cloud diagnostic support from satellites and radars are the tools for Quantitative Precipitation Forecast. But conventional methods, as were deployed till recently, essentially depend on climatological analogues of past events and weather pattern matching. Three major studies have been recently done for the river basins of Yamuna, Mahanadi and Narmada using the conventional methods. The proposed XII Plan augmentation in observational and predictive capabilities will make the ensuing studies for other river basins more accurate and reliable.

Outlays for implementing programs during the XII Plan as estimated by IMD amount to Rs 2250 crore (Table 2)

Table 2: Proposed outlays for Improvement of Agro met data in the XII Plan

S.N	Program	Total outlay (Rs crore)
1	ARG 40,000 @ Rs 2.00 Lakh each inclusive of maintenance *(2500 stations of IMD shown here but accounted in their XII FYP proposal)*	800
2	Data management, computer hardware etc. & Training	85
3	DWR 43 No, including maintenance and processing facilities *(Accounted for in IMD XII FYP proposals)*	1300
4	• 130 Lysimeters (ET) @ Rs. 5 lakh each station • 620 Soil moisture @ Rs 8 lakh each station including maintenance *Accounted for in IMD proposals*	6.5. 49.6
	Total	2241.10

3. WATER RESOURCES POTENTIAL

3.1. Estimates of average annual water resources potential

The first ever assessment of the water resources potential of Indian rivers was made by the First Irrigation Commission (1901–1903): it estimated the average annual flow of all river systems to be 1443.2 km^3 (BCM). Four decades later, A.N. Khosla, who headed the then newly constituted Central Water and Power Commission, used an empirical equation relating surface run-off to rainfall and evaporation (postulated as a function of temperature) to estimate the average annual water resources potential in six regions. The sum of the regional estimates added up to a total annual water resources potential of 1673 BCM for all rivers in the country.

The Commission has since undertaken a number of studies to improve the methodology, database and estimation procedures. The surface flows of the Indus Basin had been estimated as a key input for the agreement on water sharing between India and Pakistan. During the period 1952–1966, the CWC made a number of studies to assess the surface water resources of 23 basins and sub-basins based on statistical analysis of flow data wherever available and rainfall–run-off relations wherever they were meager. There were few terminal discharge measurements before the mid-sixties. The density of rainfall measurement stations was low and instruments/measurement protocols were not standardized. Parameters of rainfall–run-off equations were based on scattered studies made for the design of various new projects that were taken up during the period based on certain standard empirical formulae on the relation between rainfall and surface flow in vogue at that time. Systematic studies to assess the relative merits of different formulae and validation of parameter values have been limited. As of 1961, the estimated average water resources potential in the country was placed at 1881 BCM. This is close to the figure (1888 BCM) published in the report of the Irrigation Commission (1972).

During the 1970s, special studies were undertaken to generate data for the Ganges and Brahmaputra organizations and for tribunals entrusted with the task of allocating the waters of the Godavari, Krishna and Narmada rivers between the riparian States, and also for a special Fact Finding Committee on the Cauvery. These were extended to all other major basins based on statistical analysis of available flow data and rainfall–run-off relationships which had improved but were still inadequate. In the mid-eighties, when the basis and methodology of assessment were reviewed, terminal discharge observations were available for 20–25 years for eight major basins (excluding Indus, Ganges and Brahmaputra), but for fewer years in smaller basins. Estimates for peninsular rivers were based on rainfall–run-off relationships. At this time the importance of making adjustments for percolation of water in the soil, evaporation and evapotranspiration was explicitly recognized. This culminated in a major exercise, during the mid-nineties, to reassess the country's water resources potential (see annexure 8 for a review of the evolution of the basis and methods of assessing water resources potential).

The 1993 reassessment was based on a significantly different and conceptually better, more objective methodology. It sought to estimate the natural, normal flow in a basin by adjusting the observed flows at its terminal site for upstream extraction of surface and groundwater, both for irrigation and non-irrigation uses, evaporation and seepage losses, groundwater recharge (from both surface and groundwater), increase in storage, reservoir evaporation and return flows (see Annexure 9 for details). The scope and quality of basic data had also improved. And yet, the estimates of average annual water resources potential both overall (1869 BCM) and for major basins are more or less the same as the earlier ones (see table 3). This calls for a rigorous sensitivity analysis of the additional datasets that have been added since.

Part of the reason is that the revised methodology was not used for all basins: reassessment was not made for the Indus, Ganges–Brahmaputra–Meghna, Narmada, Mahanadi and Cauvery since assessment of the water resources potential has been carried out in recent times by various agencies on the basis of actual flow data. Apart from the above five basins reassessment was also not considered necessary for three basins, namely west-flowing rivers of Kutch and Saurashtra, including Luni; areas of inland drainage in Rajasthan desert, and minor rivers draining into Myanmar (Burma) and Bangladesh. In other major basins, the time series of terminal flows and estimates for other components that go into the estimation are relatively short, ranging from 6 to 17 years, ending in the mid-eighties in most cases.

The quality of estimates depends on the quality of available data on various components as well as the scope of the analytical methodologies adopted, and uniformity of the protocols followed for their generation. Measurements of water extraction from upstream storages and diversions are made by the State agencies. There are issues about coverage of these data, their reliability and the States' cooperation in making them available to the CWC. Groundwater extraction figures are estimates and not based on measurements of actual volumes pumped. Estimates of water used for non-irrigation purposes again are based on normative assumptions. The database for assessing non consumptive evaporation and 'return flows' from different uses is inadequate.

The CWC is conscious of the conceptual, methodological and data limitations of estimating the country's water resources potential**.** Over the years considerable efforts have been devoted to addressing these problems. A considerable amount of resources and efforts have gone into expanding and strengthening the National hydrological observation network consisting of: (a) observation stations to monitor one or more parameters such as gauge, discharge, sediment and water quality, and (b) project-specific hydrological observation networks. Currently, under the regular hydrological network, there are 873 stations spread across 20 basins, of which 578 are equipped to measure daily discharges. The project-specific stations also observe similar data, but for a shorter interval of time, for specific purposes such as preparation of DPR or for carrying out certain studies. Suspended sediment samples are collected once in a day along with discharge measurements and analysed in laboratories. These data are then used to estimate the total load being carried by the river.

The Hydrology Project Phase-I , whose objective was to develop a sustainable Hydrological Information system in peninsular rivers basins funded by World bank through the Central Government. Under this program modern infrastructure facilities for observation of Hydro-meteorological data and Ground water data were created in the peninsular states including Orrisa, Gujarat and Madhya Pradesh.program. The responsibility for maintenance of the equipment and facilities, taking measurements and recording of data as per prescribed protocols vests with the State Government agencies. The States are required to regularly transmit all the the data on a regular basis to the CWC. But the failure of the State agencies to do so, and their reluctance to contribute to building a National Water Resources Information Center on surface water resources is proving to be a serious problem that needs to be addressed by a combination of measures to persuade the States to comply with statutory obligations and incentives to fulfill them.

There is considerable room for improving the empirical basis for both estimation of rainfall–run-off relationships taking due note of the impact of improved coverage and quality of met observations. The new model adopted in the 1993 exercise can be improved by expanding the coverage and quality of extractions from upstream dams/diversions using more up to date time series. Systematic surveys are needed to determine the magnitude of the volume of groundwater actually pumped, consumption for various non-agricultural uses, and the parameters of return flows and non-consumptive uses. These studies must be so planned as to capture significant differences across agro-climatic regions. The determination of the last mentioned elements individually presents considerable difficulties which could be made more manageable by focusing on the estimation of consumptive use (as distinct from gross usage) in agricultural and non-agricultural sectors, and dealing with the decomposition of the residue into different elements and exploring their determinants.

The CWC is currently in the process of implementing, jointly with NRSC, a pilot research project to assess the water resources potential in two basins, namely the Godavari and Brahmani-Baitarni, based on ‘a comprehensive water balance-based approach’ using current data and prospective future changes in climatic factors and water requirements. The proposed methodology and estimation procedures were presented to the WG (see Annexure 10). Some critical observations were made by the members. The induction of some select non-official and academic experts into the advisory group responsible for formulating its conceptual framework and operational arrangements, for assessment and validation of data generated by the project and for their analysis and interpretation deserves serious consideration.

Table 3 Average annual water resources potential of river basins in India

Sl. No.	River basin	Catchment area (km^2)	Average water resources potential (BCM)*	Utilizable water resources (BCM)**	
				Surface	Ground water
1	Indus	321,289	73.3	46	26.5
2	Ganga–Brahmaputra–Meghna				
	(a) Ganga	861,452	525	250	171
	(b) Brahmaputra	194,413	537.2	24	35.1
	(c) Barak and others	41,723	48.4		
3	Godavari	312,812	110.5	76.3	40.6
4	Krishna	258,948	78.1	58	26.4
5	Cauvery	81,155	21.4	19	12.3
6	Subernarekha	29,196	12.4	6.8	1.8
7	Brahmani–Baitarni	51,822	28.5	18.3	4.0
8	Mahanadi	141,589	66.9	50	16.5
9	Pennar	55,213	6.3	6.9	4.9
10	Mahi	34,842	11	3.1	4.2
11	Sabarmati	21,674	3.8	1.9	3.0
12	Narmada	98,796	45.6	34.5	10.8
13	Tapi	65,145	14.9	14.5	8.3
14	West-flowing rivers from Tapi to Tadri	55,940	87.4	11.9	8.7
15	West-flowing rivers from Tadri to Kanyakumari	56,177	113.5	24.3	9.0
16	East Flowing rivers between Mahanadi and Pennar	86,643	22.5	13.1	9.0
17	East-flowing rivers between Pennar and Kanyakumari	100,139	16.5	16.5	9.2
18	West-flowing rivers of Kutch and Saurashtra, including Luni	321,851	15.1	15	11.2
19	Area of inland drainage in Rajasthan	---	Negligible.	--	--
20	Minor Rivers draining into Myanmar (Burma) and Bangladesh	36,202	31	--	18.8
	Total		1869.4	690	431.3

CWC Publication Reassessment of Water Resources Potential of India, 1993.
CWC Publication Water Resources of India 1988.

Table 4 Details of the data related activities of CWC:

Sl. No.	Item	Details
1	Hydrological data	The CWC maintains a countrywide network of 878 hydrological stations spread over all major river basins, where discharge, river levels, sediment, water quality data, etc. are observed. A number of other basic parameters like river velocity, wind direction, river X-section etc. are also observed to calculate the discharge. Besides hydrological data, the CWC at a limited number of stations also observes and records various meteorological data like rainfall, snowfall, evaporation, etc.
2	Publication of data	All the hydrological data observed are published basin wise in the form of Water Year Book, Sediment Year Book, and Water Quality Year Book.
3	Validation of data	All hydrological data are subject to primary and secondary processing, using standard software, SWDES and HYMOS, before being published in the form of Year Books.
4	Standards and Protocols	Before HP-I, all hydrological data were kept as hard copy in the form of Year Books or in various data forms. Some of the data which were computerized were in different formats, i.e. MS Word, MS Excel, etc. with no standard tables. SWDES developed during HP-I has now become the standard software for entry of water resources-related data and is used widely at both Central and State levels (HP-I States). All hydrological data of the CWC are now being computerized through SWDES, including most of the historical data. In order to have a safe and secure storage along with easy retrieval of all the hydrological data, WISDOM software developed during HP-I is being used at the data centers of the CWC and the States. All the technical support for SWDES is being provided by the CWC.
5	Flood forecasting	The CWC operates 175 flood forecasting stations including 28 inflow forecasting stations throughout the country. Flood forecasting is one of the most effective non-structural measures of flood management.
6	Real-time data acquisition and transmission	Real-time data have much significance in formulation of flood forecast and monitoring of floods. To achieve this, modernization of data acquisition and transmission system through satellite communication is being carried out by the CWC since the IX Plan. At present, 210 stations have been equipped with telemetry system and another 200 stations are currently being equipped.
7	Reservoir monitoring	The CWC monitors storage position of 81 major reservoirs of the country having 152 BCM of storage. Most of the data are obtained from the State authorities and a weekly report is published and circulated to all concerned regularly.
8.	Preparation of PMP atlas	The CWC has prepared PMP atlas for a number of basins e.g. Cauvery, Godavari, Narmada, Chambal, Indus, Krishna, etc. with the help of IMD and envisages preparing PMP atlas for Ganga and Brahmputra basins also.
9.	Irrigation efficiency data	Irrigation sector is the biggest user of freshwater and even a marginal increase in using irrigation water would make available a sizeable quantity of water which can be used for different purposes, including additional irrigation. Work is underway to have a databank related to water use efficiency of all major and medium projects, which will cover reservoir-filling efficiency, conveyance efficiency, on-farm application efficiency, drainage efficiency, etc.

3.2. Utilizable Resources

The above estimate relates to potential water availability from both surface flows and from groundwater. Not all of it can be utilized because of physical, technological and economic constraints. Though these two sources are interrelated, their utilizable volumes have been estimated independently: surface water by the CWC and groundwater by the CGWB. Because of this, questions have been raised whether the sum of these two estimates measures the total volume of utilizable water resources[2]. The issues involved are being deliberated by experts in other forums.

3.3. Surface flows

The CWC estimates the potentially utilizable volume of surface water in the country at 690 BCM. This is the same as shown in the 1976 report of the National Agricultural Commission and in subsequent exercises undertaken by the CWC in 1988 and more recently in 2001. The estimates for most major basins made at different times have also remained more or less unchanged. This figure was also adopted by the National Commission for Integrated Water Resources Development Plan. This does not include the possibility of increasing utilization through inter-basin transfers by the interlinking of rivers and lifting of water from river flows, the potential for which is now considered by the CWC to be substantial.

Where, by what means and on what scale surface flows can be diverted or stored, however, depend on the geography, the state of civil engineering technology for the construction of storages to acceptable standards of safety, especially in areas prone to high seismicity, the costs of construction relative to the benefits in terms of increased agricultural production, ensuring adequate supplies of water of good quality for human consumption, commercial and industrial establishments, generation of electricity and ecological sustenance. Potential projects in transnational rivers are contingent on agreements between riparian countries on the management of systems and sharing of costs and benefits. It is worth noting that projects ‘under consideration’ have an estimated storage capacity amounting to 40% of completed and ongoing projects, a large part of them is on international rivers in high seismicity regions. The growing recognition of the role of rivers and river systems in maintaining a healthy environment and the impact of expanding surface irrigation through large storages and inter basin transfers has to be factored explicitly into such assessments.

The WG was unable to locate any document explaining the basis for estimating utilizable flows. Reference was made to an early CWPC exercise based on detailed study to identify potential storage sites and their capacities in all major river basins and their sub basins. These studies are no longer traceable. Nor do they find any mention either in the Irrigation Commission report or in any accessible CWC documents on water resources assessments. In the course of one of the presentations made by the CWC, it was suggested that the latest estimate of 690 BCM is based on specific data for existing, ongoing and ’under consideration’ projects.

Details of the scope and methodology of reassessments made by the CWC since 1976 are not available. Estimates of utilizable flow in each river basin/sub-basin are

[2] This issue has been raised by Garg, N. K. and Hassan, Q., Alarming scarcity of water in India, *Curr. Sci*., 2007, 93, 932–941.

reported to have been reviewed by a Working Group constituted by the CWC in 2001. Our group was informed that utilizable flow in each basin was computed based on average annual and 75% dependable annual flow and the expected requirement in 2025 in each basin assessed by various organizations for irrigation, domestic, livestock and industrial purposes. For basins where tribunals awards exist, flows allocated by the awards are taken as utilizable this exercise was also done at the sub-basin level to distinguish those that have a surplus from those that are likely to be in deficit.

For surplus sub-basins, utilizable flow in 2025 was restricted to projected requirement for irrigation, domestic, livestock and industrial purposes within the .basin. Wherever possible, surplus flow in upstream sub-basins was considered as utilizable in downstream sub-basins, if there is storage. The average annual utilizable flow in sub-basins has been limited to 80% of average annual surface flow in the rivers. Estimates for all sub-basins and basins are not based on 75% dependable flows. In many cases (especially deficit basins and drought-prone areas), the assessed volume of utilizable flows is at a lower levels of dependability. However, it should be noted that this has not made any difference to the estimated utilizable flow for major basins.

Pressure to achieve wider spatial diffusion of the benefits of irrigation has led to the launching of projects in excess of what can be accommodated within the available funds with the State Governments, without paying adequate attention to their impact on the environment and by way of displacement of communities. [The argument for inter-basin transfers through interlinking is also based on wider distribution of surface water resources.] That there are strong pressures for constructing more projects to achieve wider diffusion of irrigation in backward regions is evident from the fact that as many as 553 projects under implementation are unapproved.

The Planning Commission and independent scholars have underscored these as the root cause for the huge overhang of unapproved projects, and the enormous delays in completing projects and realizing their design potential. The extent to which these pressures would impact on rational and prudent utilization of surface flows and the recognition that the country is facing an increasingly serious water crisis, underscore the importance and urgency of a rigorous and transparent review of the methodological and empirical basis for assessing utilizable potential of surface water and for techno- economic evaluation of projects. This is necessary to suggest ways in which these approaches could be greatly refined by a transparent handling of the attendant tasks using available knowledge and meticulous tests of consistency to ensure equitable, sustainable and economical utilization of available resources. We strongly recommend that the Planning Commission entrust these tasks in association with the official agencies to independent water scientists and professionals of wider expertise, experience and sensibility to the crucial issues of water resources development in a broader and longer term perspective.

The existing plan schemes of water information system needs to be strengthened for not only addressing the data gaps on above issues but also for proper assessment of Water Quality, Climate Change studies and fulfilling the requirement of National Water Mission.

As such, in the XII Plan, a new organization namely National Water Resources Information Centre (NWR–IC) is proposed comprising professionals from the specialized fields, namely: Water Resources, GIS, Remote Sensing, Computer Science and other related disciplines to manage the large volume of data on water resources and allied fields generated under India-WRIS project and also to update periodically for proper decision making.

Considering WMO guidelines the existing Hydrological Observation (H.O.) stations are far below the minimum requirement. In total 1917 additional H.O. stations may be opened in order to meet the minimum requirement of H.O. stations for achieving various goals such as assessment of basin wise water availability, study of climate change, better flood forecasting, flood mitigation, reservoir inflow forecasting, water quality and sediment assessment, morphological studies, planning and design of water resources projects, assessment of navigational potential for inland waterways etc. Besides, it is proposed to have water quality sample collection and analysis facilities at 810 sites out of 1917 sites proposed to be opened. The above activities would require enhanced manpower and infrastructure development and is possible only with expansion/restructuring of CWC.

The following are the proposals made by the CWC for the XII Plan to improve estimates of overall and utilizable surface water resources potential:

1. Expansion and up-gradation of the existing 878 hydrological observation (HO) stations and supporting infrastructure in site offices for repair and maintenance.

2. Setting up additional stations at 1917 sites (1107 GD and 810 GDSQ). All these stations shall be equipped with measuring gauges to make, discharge measurements as well as of some selected meteorological parameters. 810s of such sites shall be equipped with measuring systems to monitor silt load and water quality.

3. Opening, R&M and up-gradation of water quality laboratories for monitoring water quality at the existing 371 and additional 810 water quality stations.

4. Facilities for monitoring glacial lakes/water bodies and snow-melt forecasting in the Himalayan region.

5. Expansion in the number of reservoirs equipped for telemetric monitoring of reservoir water level and live storage.

6. Creating a Coastal Management Information System (CMIS) for collecting data on various natural phenomena occurring in coastal regions, and for appraisal and monitoring of projects for their protection.

7. Setting up a new organization, namely National Water Resources Information Centre (NWR-IC), comprising professionals with specialized expertise in water resources, GIS, remote sensing, computer science and other related disciplines to manage the large volume of data on water resources and allied fields generated under India-WRIS project and also to update periodically for proper decision-making.

8. Strengthening in-house facilities for upgrading capacity for digitized management and dissemination of data.

Implementing these recommendations during the XII Plan is estimated to require an outlay of Rs. 3850 crore. (Table 5)

Table 5: Proposed XII Plan outlays for improvement of surface water data

(Rs. Crore)

I)	Expansion and modernization of hydrological observations, including snow hydrology, water quality and monitoring of glacial lakes	3300
II)	Coastal Management Information System	180
III)	Strengthening of monitoring unit in the CWC for AIBP-assisted projects and to assess irrigation potential by remote sensing techniques	170
IV)	NWRIC	100
V)	Water Quality Assessment Authority	60
VI)	Up-gradation and modernization of IT and Library Information Bureau	23
VII)	Telemetry-based monitoring of reservoir level and live storage	24
VIII)	In-house data bank and Online Information System	5
	Total	3862

Proposed outlays on sample surveys and research, which need to be done through academic and research institutions, are indicated in chapter 5

Needless to say, the scale and content of these programs and outlays are indicative. Their scope and content, as well as priorities will of course be decided after the detailed programs are worked out and scrutinized in the light of the numerous suggestions make in this report.

For instance, while our group strongly endorses the concept of NWRIC being located in the CWC, the details of its scope, organization and management need to be decided after an independent review.

The above list does not include our suggestion for installation of telemetric monitoring of actual water deliveries in major surface projects.

More importantly, we are of the view that the Planning Commission should constitute a group of independent and experienced water scientists and professionals to carry out a rigorous and transparent review of the methodological and empirical basis for assessing the utilizable potential of surface water and for techno economic evaluation of projects.

3.4. Groundwater resources

The CGWB is the authority that provides data on the potential availability of groundwater and its use. According to its latest assessment, the total utilizable volume of groundwater in the country is 432 BCM of which, allowing for non-agricultural uses, 360 BCM is estimated to be available for irrigation. Actual use of utilization for irrigation is placed at 115 BCM. These estimates imply that barely a third of groundwater potential is being utilized and that there is substantial unutilized potential for further expansion. By comparison, the potential utilizable volume of surface water is placed at 690 BCM, of which nearly 70% (450 BCM) is estimated to be currently utilized. On the basis of the available data, current levels of groundwater utilization are nearly thrice the estimated level in 1951 (40 BCM) while over the same period surface water utilization is estimated to have quadrupled from 115 BCM to 450 BCM.

Though in terms of volume the groundwater use has grown at a slower pace, the area reported to be irrigated by groundwater has grown much faster (more than six fold according to the Planning Commission) than the area irrigated by surface water (which increased only two and a half times during this period). According to these data, the share of groundwater in total irrigated area has risen from about a third in 1951 to over 50% currently. More than 60% of the increase in irrigated area is attributed to groundwater.

A crucial gap in the estimation of groundwater exploitation (and consequent use) is that all data available with the CGWB are based on the 'monitored and controlled' data obtained by the organization. There is a significant gap in this, since most of the 'privately created' wells (dug wells and bore wells) do not find inclusion in these records. The actual extraction of groundwater is far larger; the dependence on groundwater for agricultural, industrial and domestic uses can be shown to be far larger than the official figures, as evidenced by some case studies.

There is thus a large divergence between the growth of utilization by volume and that of area irrigated by the two sources. Moreover, even as estimates of water potential point to a large scope for expansion of groundwater use, evidence of increasingly widespread and progressive deepening of wells and lowering of water tables is causing widespread concern about over exploitation of this resource. It is obviously important to understand the reasons for these differences and come to a definitive assessment of groundwater potential, the current rate of its exploitation for irrigation and other uses, and of the incidence and intensity of over exploitation.

Table 6: Net irrigated area and water used for irrigation from surface and groundwater sources in selected years*.

	1951	1968	1997
NIA LUS [1] (m ha)			
Surface	14.9	19.3	23.8
Groundwater	6.0	10.4	30.4
Total	20.9	29.7	54.2
GIA PC [2] (m ha)			
Surface	16.1	23.3	36.2
Groundwater	6.5	12.5	40
Total	22.6	35.8	76.2
Water utilization (BCM)			
Surface [2]	115	400	450
Groundwater [3]	40	85	105
Total	155	485	555

[1] Estimates of NIA for all years are from land - use statistics.
[2] CWC, Water related statistics, 2008(page 143, table 2.1.).
[3] Estimates of surface water utilization for all years and groundwater utilization for 1968 and 1991 are CWC estimates. For 1951, on an assumed irrigation depth of 1.5 m

3.5. Current status of data

The CGWB is the principal agency responsible for assessment of groundwater potential and its exploitation in the country as well tracking trends in its utilization. It has done a considerable amount work to develop, test and refine the conceptual framework and estimation procedures for this purpose. These were recently revised in 2008 after extensive deliberations with expert hydro-geologists and form the basis for the current estimates of potential and utilization (for details see annexure 11). The main features briefly are as follows:

The ultimate source of all renewable groundwater resources is rainfall. In any given region, a part of the local rainfall seeps through the topsoil and recharges underground aquifers. This is called direct or natural recharge. In addition, groundwater is indirectly recharged by: (a) lateral seepage from rivers, streams and other natural water bodies in contiguous areas, and (b) seepage of water supplied by canals in the command area of surface-water projects.

The rate of natural recharge depends on rainfall (level, intensity and temporal distribution), characteristics of the topsoil and sub-surface geology. These have been estimated on the basis of detailed field measurements of infiltration rates at the watershed level under different agro-climatic and geological conditions. These estimates are made on the basis of normal rainfall. The parameters of indirect recharge from other sources are also based on field studies in different locations.

Natural recharge can also be estimated by deducting the volume of indirect recharge from different sources from the change in the total volume of water between pre- and post-monsoon seasons in wells monitored by the CGWB and SGW departments, in the assessment area (the product of change in water level of wells in the assessment area during this period and the area of the assessment unit and its water holding capacity). The two estimates of natural recharge are cross-checked before finalizing the estimate of recharge.

The annual replenishable groundwater resources are the sum of the estimated volumes of direct and indirect recharge. From this 5–10% is deducted to allow for natural discharge during the monsoon season to arrive at the net annual volume of groundwater available for all uses. Future long-term requirements for domestic and industrial uses (estimated on the basis of projected growth of rural and urban population and industries, and consumption norms for these uses) are deducted from this to arrive at the volume available for irrigation.

The last estimate published in 2004 placed the total groundwater recharge in the country at 433 BCM, made up of 289.86 BCM from rainfall recharge, and 142.78 BCM from recharge from other sources like rivers, canals and return flows. Deducting an estimated 72 BCM to meet groundwater requirements for projected long-term needs of non-agricultural uses, the potential availability for irrigation is placed at 360 BCM. These estimates are revised every five years.

The scope and current status of studies on which these estimates are now based are given in table 7 below (Annexure 11 gives details of the evolution of the CGWB methodology and improvements for assessing groundwater potential.)

Table 7 Present status of data generation

Sl. No.	Items	Status
1	Sub-surface geometry of aquifers	• Based on the country-wide groundwater surveys, and groundwater exploration data generated by the CGWB and other organizations, the hydrogeological map of India on 1:2,000,000 scale was first prepared in 1982 and subsequently revised in 2002. • Aquifer dispositions have been delineated in limited water balance project areas in different hydrogeological environments of the country covering ~10% of its total geographical area, based on point data and interpolation of lithology with aquifer characterization. • Lithological and geophysical logs of ~12,000 exploratory wells are available with the CGWB similar data available with the States need to be ascertained. • Aquifer parameters determined through pumping tests by the CGWB and the States.
2	Groundwater level monitoring	• 15,000 groundwater observation wells are monitored by the CGWB four times a year. 3500 of these are piezometers with depths ranging from 40m to 100m, whilst the remainder is open wells/dug wells. • Nearly 40,000 wells are monitored by various States, with frequency varying from twice a year to monthly measurements. • A limited number of digital water-level recorders are functional in some States with high frequency data. • Datasets relating to projects/studies carried out by academic institutions and research labs are also available in some cases.
3	Mapping of the specific yield parameter	• Specific yield of selected lithological formations has been estimated through field tests: pumping tests, dry season water balance and numerical modeling technique. These have been recommended as specific yield norms under GEC-97. • Dedicated projects by the CGWB/States have been taken up to determine specific yield in some of the States.
4	Determination of rainfall–recharge relationship	• Rainfall infiltration factors of selected lithological formations have been estimated through field tests. These have been recommended as norms under GEC-97. • Data of infiltration tests carried out by the CGWB and other agencies may be available. • Data from studies performed by agricultural institutions and universities may also be available.
5	Determination of seepage factors (canal, irrigation return flow, tanks and ponds, water conservation structures)	• Three type values of canal seepage factors have also been recommended based on soil types and lining of canals. • Six norms each of surface irrigation return flow and groundwater irrigation return flow have also been determined based on field studies.
6	Groundwater discharge estimates	• Base flow estimates in some watersheds/ sub-basins may exist with the CWC/ surface water agencies of the States. These can be used to estimate groundwater discharge for specific lithological units.
7	Groundwater quality data	• 15,000 groundwater observation wells are monitored by the CGWB once a year. • In addition, one-time data on water quality are also collected during survey and exploration by the CGWB.

Sl. No.	Items	Status
		• Data from the States need to be ascertained. • DWS, MoRD has hamlet-wise/ scheme-wise, one-time data on water quality, but these are not yet geo-referenced. • Limited data are available with CPCB/SPCB. CPCB is monitoring ~ 490 wells half-yearly. • Water quality data are also available with local bodies / PHED.
8	Reliable groundwater utilization (i.e. pumping) figures	• A number of groundwater abstraction structures for minor irrigation are being generated through the MoWR scheme on Minor Irrigation Census. • In addition, State Governments are also carrying out well census studies. • Utilization is being assessed by the States using groundwater structure-wise unit draft. • Some States use the cropping pattern method to compute groundwater utilization for irrigation.

Data currently being generated are inadequate to provide reliable estimates of groundwater potential and utilization. The following are the major gaps and limitations in the current methods for collection and use of data.

1. The CGWB estimates of natural recharge from rainfall are reported to be based on normal rainfall as well as on averages of observed changes in the pre- and post-monsoon water-table levels over 5-year periods. It is surely possible to make both estimates for monsoon and non-monsoon seasons on an annual basis to permit a more rigorous comparison of the two estimates and also track changes over the years.

2. Aquifer geometry in three dimensions is the starting point for constructing a model of the groundwater system. This is, however, poorly known over 90% of the country, and constitutes the fundamental inadequacy in applying analytical tools to simulating the dynamic state of the aquifers for designing conservation and protection measures. The scale of mapping of sub-surface geometry of the aquifers currently available is far too large to be of much practical use. Finer-scale mapping of aquifer disposition is as yet limited to very few areas. Estimates of key parameters that affect recharge, namely rainfall–infiltration relationships, seepage rates from canals, water bodies and irrigation, groundwater discharge and specific yield – are based on limited ad hoc studies in a few locations, rather than systematic studies to cover different agro-meteorological conditions.

3. The quality of data and their usability are also affected because data-generating protocols across institutions are not standardized; they are not geo-referenced; there are no systems for validating and archiving data for easy classification and retrieval, and the lack of inter-institutional mechanisms for data sharing among various agencies that generate and collect data at great expense. Even where agreed protocols exist, such as for the National Hydrology Project, the failure to operationalize them results in continuing value loss of the data being generated.

4. Estimates of groundwater potential and use are currently based mostly on data collected from some 55000 observation wells. When compared with the estimates of

wells numbering more than 7.6 million (CGWB compilation, 2004), this number is statistically insignificant to provide cognizable estimates.

5. Changes in water level of the observation wells between pre- and post-monsoon periods give an indication of how much direct and indirect recharge has taken place during a given year. This could be influenced by the pre-monsoon level of the water table, which is the carryover from the previous year. The post-monsoon depth of the entire water column would give a measure of the water available in the well. If both are being monitored, the time series of such data can be used for rigorous analysis of: (a) the impact of pre-monsoon storage and rainfall on the magnitude of incremental recharge; (b) the long trends in the post-monsoon depth of the entire water column, and (c) whether the correlation between depth of water column in different locations in hard-rock regions differs significantly from that in regions (like the Indo -Gangetic Plains) where the aquifer zones are more continuous and homogenous.

6. Compared to wells/tube wells in active use, observation wells are few in number, and do not constitute an adequate and representative sample of wells/tube wells in use, which are generally much deeper and distributed over widely varying agro-climatic and sub-surface geologic conditions. The number and location of observation wells have not been chosen in a systematic way to provide a reliable estimate of total natural recharge/water-level fluctuations in the assessment units (500 km^2 in hard-rock areas and districts/blocks in alluvial tracts).

7. The characteristics (depth of water table, water column and changes therein) in the observation wells are believed to provide a reliable idea of the characteristics of the wells in use that tap the same aquifer. This is plausible in the case of deep and continuous aquifers of the type seen in the Indo-Gangetic Plains. Whether this presumption is also valid in hard-rock regions needs to be established. This can be tested by comparing the profiles of water table and water column in selected observation wells with those of wells in active use in their close proximity. Current estimates of recharge are made for assessment units with an average area of 500 km^2. They are inadequate for assessing potentials, utilization and proper management of groundwater at the level of micro watersheds and village communities.

8. Given the wide variations in the characteristics and conditions of groundwater aquifers, specially in the hard-rock regions, it is important to focus on wells/tube wells actually in use and the aquifers from which they draw their supplies. The Minor Irrigation Census gives detailed village-wise information on some characteristics of wells and tube wells in use – notably depth, energized equipment and total and crop-wise areas irrigated. Such information is available for three past censuses. These could be used to get a rough idea of the characteristics of aquifers across and within different agro-climatic regions.

9. There are no studies of the behaviour of water levels in wells/tube wells actually in use along the lines being done in the case of observation wells. Techniques and methods for mapping and classifying aquifers, determining their water storage capacity, actual recharge and utilization across seasons and years have been developed. But these are yet to be used for systematic field-level studies.

10. It must be emphasized that the information value of the various existing (and future) datasets relating to groundwater (lithologs, geophysical images, aquifer parameters, etc.), generated by various agencies: Central, State, academic and research institutions, can be greatly enhanced simply by pooling these, and fusing them after analytically screening for quality. To begin with, it would be far more productive if the States established a common platform for all sources of water. Surface and groundwater departments would thus be able to seamlessly share stream flow and groundwater levels, to gain a far better and intimate understanding of the linkages between surface and groundwater flows, and design reliable integrated methodologies for estimating the storages of and fluxes between the various hydrological-cycle components.

11. Failure analysis of existing protocols, notably those developed under the yet to be realized Hydrology Project -I, especially conceived for development of tools for data sharing and management, should help formulate better workable strategies. However, this goal still remains to be realized.

12. Careful design of formats for data recording and archiving aimed at eliminating ambiguity in geo-referencing and standards, is another easily attainable goal that would go a long way in enhancing the information value of data currently being generated. For example, geo-referencing of data sites with respect to GPS coordinates and/or census villages, would help eliminate avoidable confusions that often arise from the commonality of locale names.

The existing system is clearly inadequate to provide requisite, reliable and validated data on groundwater resources and their utilization at a sufficiently disaggregated level. The kinds of data that need to be generated on different aspects, the methodologies to be used, and the desirable (ideal) scale/frequency at which they need to be generated to build a comprehensive database are set out below:

- Subsurface maps of aquifers to establish their geometry, with aquifer boundary depths determined with an uncertainty less than 10%, using a conjunction of state-of-the-art geophysical technologies for both creative experiment design and incisive analysis.

- Monthly groundwater-level data at an optimally distributed network of ~100,000 monitoring wells in the country to be generated, of which 20% be equipped with DWLRs.

- Annual maps of the specific yield parameter to be prepared for each assessment unit prior to each estimation year along with periodic evaluation of the estimation methodologies.

- Rainfall–recharge relationship to be determined for each agro-climatologic zone along with periodical evaluation of the estimation methodologies.

- Groundwater-level data along canals and around other storage structures together with the respective surface water-level data for the determination of seepage factors.

- Groundwater discharge estimates for each assessment unit.

- Groundwater quality data: geogenic and anthropogenic through seasonally sampled groundwater quality data at the Panchayat level.

- Reliable groundwater utilization figures (i.e. pumping, disaggregated by industrial, agricultural and domestic uses), and their temporal variations during the year, through metering.

The key elements of an effective plan for meeting these requirements are set out below.

Subsurface maps of aquifers to establish their geometry.

- A comprehensive plan adopting a top down approach needs to be formulated to map the aquifer geometry with high enough resolution. The issue related to countrywide aquifer mapping has already been deliberated in the 'Working Group on Sustainable Ground Water Management' constituted by the Planning Commission under the Chairmanship of Dr Himanshu Kulkarni. Under this group, a detailed XII Plan proposal is being formulated for aquifer mapping in India. The most feasible approach to rapidly complete a countrywide reconnaissance survey of aquifers for a first-stage characterization, would be through the now available helicopter-borne time domain electromagnetic exploration.

- Pilot project of micro-level aquifer mapping in five different hydrogeological terrains has been initiated by the CGWB in collaboration with NGRI and NRSC, at an estimated cost of Rs 32 crore with an objective to establish detailed methodology for aquifer mapping at the micro level. It is strongly recommended that this work be redesigned by exploiting the potential of greatly improving the resolutions through a conjunctive use of electrical and shallow seismic technologies, not included in the current Plan. Further, downscaling of aquifer mapping below the 1:50,000 scale may be taken up on a priority basis, depending upon the necessity and after establishing the data gaps, to characterize complex aquifer systems.

- Obtain knowledge of the characteristic properties (flow and transport) of the aquifers e.g. permeability/transmissivity, specific capacity, dispersion coefficient, storage coefficient, etc.

- Along with hydrogeology and geophysical components, we need geomorphological investigations. But these require an engagement with quantitative geomorphology, an approach now pursued the world over but not a part of the Indian earth sciences scene. Special efforts must therefore be made to create a band of quantitative hydro- geomorphologists in the country through targeted training and other ways to generate new expertise.

- Establish mechanism for data sharing among agencies custodians of data.

- Analysis of existing subsurface exploratory data; geophysical data, including logging data available with different agencies to delineate major aquifer systems, and fill data gaps with various geophysical techniques to get continuous data of subsurface disposition.

- Pilots may be taken up in hard and soft rock areas to establish the suitability of various techniques, mapping scale and reliability.

- Standard coding system needs to be developed to establish typology of aquifers. The latter is very important in understanding the geochemical and hydrogeological characteristics of groundwater

- Finally, 'a logically integrated approach' has to be designed and developed comprising hydrogeology, geomorphology and geophysics to code/classify the typology.

Aquifer characteristics

- Aquifer characteristics, viz. the flow and transport properties of the aquifer are essential for development as well as simulation of flow and mass transport.

  (a) At the very outset, therefore, the following investigations should be addressed.

  (b) Compilation and analysis of all the hydraulic tests carried out and their re-interpretation, if feasible.

  (c) Determination of the specific capacity of all existing wells using an adequately close network.

Groundwater level monitoring

- It is necessary to have adequate number of functional DWLRs with high-frequency data to establish groundwater discharge trends and the impact of various groundwater stresses in space and time.

- The aim should be to set up an optimally distributed network that would cover ~100,000 monitoring wells in the country according to a standard design of protocols, of which 20% be equipped with DWLRs.

- Monitoring of the impact of urbanization on groundwater regimes using a separate groundwater monitoring network in urban areas.

- Standardized analytical tools need to be adopted for the analysis of hydrographs and time-series data. Also, trained personnel to use these tools and data-generating agencies to routinely distil out illuminating information from the data are needed.

- Spatially adequate water-level data essential for catalysing development of analytical and software tools to catalyse community and village-level management of groundwater.

- Currently, groundwater levels are being measured at various frequencies (two times a year to 12 times a year by various State/Central agencies). Even though groundwater estimates are very critical to States such as Rajasthan, measurements are made only twice a year, introducing large uncertainties in the estimated resource.

- Alongside with improvements in methodology for estimating groundwater potential at the assessment unit level, it is necessary to explore ways to increase the capacity for such assessment at the micro watershed community level.

- The WG noted such a study done by IISc in Gundulpet taluk in Karnataka. The standard of technique and rigour that was attained in the study is both difficult and expensive to be attempted on a large scale. But such studies should be encouraged and supported in more locations on a selective basis. Some manageable combination of the two should be our objective.

- Several NGOs in different parts of the country (APFAMGS; ACWADAM; ACT; FES; PSI being notable examples) are making efforts to promote local institutions/groups involving Panchayati Raj institutions, local urban/rural bodies to assess groundwater potential and ways to regulate it. Such initiatives should be encouraged and supported. The experience of these initiatives, especially in institutionalizing them on a sustained basis and making an effective contribution to community regulation needs to be assessed in an objective and dispassionate manner. This is necessary to better understand the problems involved and devise a strategy for extending them.

- Groundwater-level measurements from the State and CGWB at various monitoring stations should be validated with measurements in wells under use to verify if the levels recorded from the long-term monitoring stations are representative of the groundwater setting.

- In a few States, under the Hydrology Project, automatic DWLRs have been installed and are functioning. These provide groundwater levels at a very high frequency in a day. These data should be used to verify if the aquifer is reacting to the groundwater use in the neighbourhood of the monitoring station equipped with automatic DWLRs.

Mapping of the specific yield parameter

- Knowledge of specific yield parameter is critical for the estimation of groundwater resource.

- Specific yield determinations for the ~6000 assessment units to be carried out and periodically refined at intervals of 3 – 5 years based on the periodicity of the assessment.

- Maps of the specific yield parameter to be prepared for each assessment unit prior to each estimation year.

- Multiple methods need to be applied for the specific yield determination.

- To start with, this parameter may be estimated using the simple inversion of the groundwater-level hydrographs in each of the assessment units.

- The estimation methodologies need to be reviewed and refined periodically.

Determination of rainfall–recharge relationship

- Multiple methods to be used for the determination of the rainfall–recharge factor.

- To start with pilot projects for rainfall–recharge factor determination to be taken up for each agro-climatic zone. Meteorological observatories and groundwater-monitoring wells fitted with DWLR should co-exist in these pilot project areas to determine the rainfall–recharge factor using well hydrograph analysis.

- Rainfall infiltration factors to be determined and periodically refined (3–5 years depending upon the periodicity of assessment) for all the agro-climatic zones categorized by the various States.

- Institutions having expertise in tracer technique/chemical methods for the determination of the rainfall–recharge factor to be collaborators in these pilot projects.

Determination of seepage factors (canal, irrigation return flow, tanks and ponds, water-conservation structures

- Groundwater-level data and canal water-level data in canal command areas located within the assessment units to be measured for determination of canal seepage factor.

- This can be done by suitably sampling villages in the command of selected surface commands using data from the Minor Irrigation Census.

- CADA mandate to accomplish this task should be enforced, by obliging it to conduct pilot experiments in type areas.

Groundwater discharge estimates

- Currently this aspect has not been studied and no estimates are available even for the larger lithological units.

- Comprehensive studies of spatio-temporal variability of this parameter need to be carried out across various assessment units or even sub-basins for assessing groundwater discharge.

- Data on changes in the groundwater level during non-monsoon season can be used for estimation of groundwater discharge.

- Alternate methods should be explored for estimation of groundwater discharge.

Groundwater quality data

- The CGWB and State groundwater departments are to be strengthened with high-resolution water-quality labs to serve as cross-verification and validation from other laboratories.

- Groundwater quality data: geogenic and anthropogenic through seasonally sampled groundwater quality data need to be collected at the Panchayat level.

- Groundwater quality data should be unambiguously geo-referenced, by adopting the convention to tie these with the ID of the census village, as for example, done by the Karnataka.

3.6. Attainable action plan for the XII Plan

The above requirements would need to be fulfilled in the medium term (a decade) by drawing up a phased program and making the best use of new available measurement, analytical and information technologies to generate the availability of trained personnel, and improving organizational arrangements. This calls for sustained initiatives to explore methodological issues in several areas.

Methodological analytical approaches for enhancing information value of data

- Alternate methodologies for specific yield, groundwater discharge, groundwater utilization and quality.

- Currently, groundwater estimation is limited to recharge estimation. But, complete models that incorporate both groundwater recharge and discharge need to be used and refined.

- Estimates of groundwater discharge at basin/sub-basin scales can be validated with the base flow computed at stream gauging sites and hence improving the reliability of groundwater resources estimation.

- Current requirement in most basins or watersheds in the country is to conserve the groundwater and restrict the depletion, and hence the approaches for the resources estimation should be focused, improved or adapted towards this direction**.** There is a need to estimate parameters of relevance in this context (e.g. storage properties at finer scale, recharge factors from artificial recharge or other conservation approaches).

Models of automated information system/service with examples

- The approach that is planned by the CGWB is broadly on similar lines as that of the USGS, and is continually being enhanced.

Experimental approaches and design (pilot projects)

- To resolve uncertainties and develop simplified methods towards wider application of groundwater data in decision-making, water exploitation practices by semi-skilled functionaries/farmers.

- Pilot projects for specific yield, groundwater discharge and groundwater utilization to be taken up in different hydrogeological set ups.

- Separate groundwater utilization projects for urban and industrial areas working with institutions such as IIM, Bangalore.

- Pilot projects on impact studies on groundwater recharge from watershed conservation practices.

- A pilot project on geophysical applications is essential to establish the aquifer geometry. Application of different techniques and scale shall be decided accordingly.

Potentially illuminating research initiatives to sharpen groundwater system models and future behaviour

- Basin scale – Surface and groundwater coupling.

- Urban water cycle – urban flooding, urban recharge and wastewater recycling.

- Climate change – surface and groundwater on a river basin scale.

Data sharing

- There is a need to establish mechanism for free flow of data between the State groundwater departments and central agencies.

- A suitable groundwater flow or coupled groundwater surface water model may be prepared and be preserved at the state level for utilization by the CGWB and the states.

- We need to address issues of bringing the State and Central groundwater boards to collaborate in building a National network, as well as their role in different activities proposed and, in particular, for detailed surveys of water extraction, use and trends in water tables in the wells actually in use.

3.7. Recommendations for the XII Plan:

- Formulate a comprehensive, phased plan for high-resolution maps of the geometry and characteristics of aquifers at an appropriate level of spatial disaggregation.

- Based on pilot studies in select areas for micro-scale mapping through collaborative approach involving agencies working in this domain, plan complete mapping on 1:50000 scale up to 200m in hard rock and 300m in soft rock over an area of 10000 km^2.

- Increase the number of observation wells from the present 50,000 to 100,000 during the XII Plan.

- Install DWLRs with telemetry in 10,000 of these wells.

- Build capacity for continuous monitoring of water levels in 40,000 observation wells.

- Determine aquifer parameters and specific yield in 500 assessment units.

- Assess actual groundwater extraction from wells in use in two selected clusters per assessment unit in all 6000 assessment units.

- Establish the mechanism of data sharing among agencies that are custodians of groundwater data.

- Efforts should be made to establish 1 lakh dedicated groundwater observation wells in the country, some of which may be monitored through Panchayati Raj institutions, urban/rural bodies. The frequency of groundwater-level measurement needs to be increased to verify if the aquifer is reacting to groundwater use in the neighbourhood.

- For determination of rainfall–discharge relationship, the pilot project needs to be taken up in each agro/hydro-climatic zone.

- Currently, groundwater estimation is limited to recharge estimation. But, complete models that incorporate both groundwater recharge and draft need to be used and refined.

- Estimates of groundwater discharge at basin/sub-basin scales can be validated with the base flow computed at stream gauging sites and hence improving the reliability of groundwater resource estimation.

- Current requirement in most basins or watersheds in the country is to conserve the groundwater and restrict the depletion, and hence the approaches for the resources estimation should be focused, improved or adapted towards this direction.

- There is a need to estimate parameters of relevance in this context (e.g. storage properties at finer scale, recharge factors from artificial recharge or other conservation approaches).

Outlays required to implement the program in the XII Plan are estimated at roughly Rs. 1450 crore. (table 8)

Table 8: Proposed outlays for improvement of data on groundwater

(Rs. crore)

Sl. No.	Activity		Outlay
1.	Expansion of observation well network	50,000 wells	1075
2.	DWLR with telemetry	10,000	150
3.	Continuous monitoring of water level in observation wells	40,000	10
4.	Determination of aquifer parameters and specific yield in aquifer units	500	30
5.	Assessment of groundwater utilization in 6000 assessment units and 12000 clusters		150
6.	CGWB sponsored R&D studies in different agro-climatic zones		30
	Total		1445

(In addition to above, outlay for aquifer mapping is being proposed by working group on Sustainable Ground Water Management' constituted by the Planning Commission under the Chairmanship of Dr Himanshu Kulkarni.)

4. DATA ON WATER UTILIZATION

4.1. Utilization by source

The focus and scope of data collection by Central and State water resources organizations are currently limited to: (i) surface flows that can be (and are) stored or diverted through relatively large storage projects, and (ii) groundwater that can be (and is) extracted. Little attention has so far been paid to monitoring water being tapped through 'minor' works by diversion and storage of surface flows, nor is cognizance taken of the role of natural rainfall in building and replenishing soil moisture storage. The latter is practically the sole source of water for crops, and trees and forests grown on un-irrigated lands. It also accounts for a significant part of water available for irrigated crops. A meaningful estimate of overall water utilization must therefore be expanded to cover both minor surface works and the direct contribution of rainfall to building soil moisture.

4.2. Rainfall

Discussions of water resources development and management usually focus on surface flows and groundwater. They rarely recognize the direct contribution of rainfall to meet the water needs of forests, trees, pastures and crops. In the absence of irrigation, these needs are met entirely by soil moisture built up or replenished by rainfall. Even under irrigated conditions, rainfall contributes a significant proportion of water requirements for these uses. A comprehensive assessment of water resources availability must therefore take explicit account of the contribution of rainfall.

The direct contribution of rainfall to building/replenishing soil moisture is difficult to estimate. It depends on several interrelated factors: (a) quantum and intensity of precipitation, and their distribution across and within seasons; (b) the nature, extent and density of vegetation being grown on the ground, and (c) depth, permeability and porosity of the topsoil. All these are highly variable across space, season and over time. The concept of effective rainfall – generally assumed to be 80% of precipitation in different seasons – as a measure of its magnitude is a gross approximation even for macro-level assessments of water balance at the basin level. It is, however, quite inadequate for assessing the current utilization and the potential for augmentation at the micro water-shed level.

Land use and productivity of the larger part of the country's land resources depend entirely on rainfall. The prospects of increasing the productivity and income of people in these areas depend crucially on the scope for making fuller and more efficient use of local rainfall. Water availability and use in rainfed areas have so far received scant attention from the CWC and therefore, no assessments of the scope for increasing its utilization chain have been made. This task under the charge of the Integrated Watershed Development program is restricted to checking soil erosion and increasing effective water availability for domestic and agricultural use through local rainwater harvesting as well as groundwater recharge structures and measures to bring about appropriate changes in land use and cultivation. Obtaining the required data for the program that covers a vast number of micro watersheds of varied hydrological characteristics is a daunting task. There are doubts about whether the needed data are in fact generated, whether they are adequate in terms of scope, content and reliability, and about the extent to which they are actually used in planning.

We recommend that during the XII Plan rigorous studies to address this lacuna be undertaken in selected watersheds in different agro-climatic regions. These studies should survey the characteristics of the soil profile, and the maximum amount of water that can be stored in the soil and underground aquifers; the actual amounts currently being stored in these forms, their seasonal distribution in normal and bad years; measures to improve soil cover, reduce/slowdown run-off, change the land-use pattern and assess the extent to which these measures can improve soil moisture and availability of groundwater (see Annexure 12).

4.3. Surface water

4.3.1. Major and medium projects

Major and medium works account for the bulk of surface water utilization. All these projects are equipped with gauges to measure the volume of water discharged from the reservoirs/diversion points into their respective canal networks. In large projects flow-level indicators are installed in main and branch canals. Officials responsible for operating each of these systems are all under the State water resources departments. They are mandated to monitor and record discharges from head works and flow levels in major canals on a daily basis. They can provide the database for estimating, even if only approximately, total deliveries of water from each of these systems. The Planning Commission's Committee on Irrigation Pricing (1991) was able to obtain season-wise water deliveries during the late eighties for some 140 projects from the States (see Annexure 13), but it took much effort and persuasion.

Furthermore, it is widely recognized that gauges and measuring devices in use by various agencies/projects, vary in their technical designs. As part of the HP, the CWC has done much to help the States expand the coverage and improve the quality of discharge measurement equipment. But the care invested in their maintenance and the rigour in following the protocols for measurements, supervision and reporting data recorded at the head of the canal network are weak. It is not known whether these data are collected regularly in all systems and whether State Governments compile them to track overall surface water deliveries. The CWC does not have the authority to monitor State agencies that collect the data, much less to oblige them to submit these to the National data pool. This is evident in the experience of the 1993 reassessment of water resources, which requires terminal flows to be adjusted for upstream extractions and the poor compliance by the States with agreements to provide such data.

Corrective measures – through appropriate changes in law with strong sanctions combined with incentives – are necessary to ensure that the States provide reliable data to the CWC on a regular basis on surface water utilization. For this purpose, it is should be made mandatory for the States to collect water delivery data for all major and medium projects and deposit these with the data repository hosted by the CWC. The CWC should also be authorized to conduct sample checks to ensure that prescribed protocols for recording and validating measurements are meticulously observed.

4.3.2. Minor surface works

The so called 'minor' surface works (tanks, ponds and water from diversion/lifting of water streams) account for a relatively small proportion of the total surface water utilization even as they are widespread and play a vital role as sources of water for domestic and agricultural uses in several hundreds of thousands of villages. The Minor Irrigation (MI) Census[3] gives data on the number of works of different kinds and the area irrigated by them. Estimates of storage capacity of tanks are available in some States, but these are incomplete and outdated. There are no measurements of the volume of water that is supplied from this category of works.

There is a widespread impression that the condition of these local works has deteriorated over time. Official statistics shows a progressive decline in the area irrigated by minor surface works. But detailed studies in some regions[4] raise doubts about the veracity of the statistics. Given their spread and the fact that they serve a huge number of communities, a special survey must be made to ascertain the current condition of minor works, changes that have occurred in recent times, and their contribution to the local water supply. The MI censuses provide a wealth of information on the characteristics of minor water works of different types, their spatial distribution and some idea of changes that are taking place. These could be used as the basis for selecting a manageable number of village's representative of different regions for in depth surveys to obtain a more reliable picture of the conditions of this category of works and their role in local water economy.

4.4. Groundwater

In the case of groundwater, the present method of estimating extraction is based on the number of wells/tube wells as reported in the MI census and assumptions about the unit draft. In the absence of any systematic survey, it is not clear whether they capture variations in the volume, annually pumped out from different types of wells in different regions. More so, because these characteristics are changing significantly and rapidly.

---

[3] GOI, Report of the 3rd Minor Irrigation Census, 2001

[4] A number of such studies have been done in, among other institutions, the Madras Institute of Development Studies. Some of their findings are reported in Tanks of South India, Centre for Science and environment, New Delhi.

Ideally we need reliable estimates of end use (disaggregated by industrial, agricultural and domestic uses) and its temporal variations at the level of assessment units. For this purpose it is necessary to adopt a differentiated strategy to collect and validate the data for different kinds of wells across regions and those used for irrigation, domestic and commercial purposes, and by different categories of industry.

Given the huge number of wells and tube wells, the only practical and reliable way to assess utilization of groundwater is through direct measurements of pumped volumes through properly designed sample surveys. In rural areas, the MI Census gives details of the number of wells and tube wells used for irrigation down to the village level. It provides a ready frame for rigorous sampling of blocks and villages within taluks stratified according to the extent of area under groundwater irrigation and characteristics of wells/tube wells. This would give a representative sample of manageable and affordable size, and one which would give estimates within low margins of error.

This exercise needs to be conducted on a regular basis as a collaborative effort between the CGWB and the SGWBs to provide estimates for agro-climatic regions, States and at the National level. It should distinguish between groundwater extraction from wells that are the sole source of irrigation and those located in canal commands and used in conjunction with surface irrigation. (Annexure 14 outlines the scope and design of such a survey.) These surveys need to be repeated periodically in all the sample wells and annually in a sub-sample of them. Besides estimating volume of extraction, these surveys should also collect data on area and yield of crops irrigated, water management practices, and depth of water tables and of water columns. More detailed village-level estimates can be left to be generated by the local communities with technical help and support from the SGWBs.

These estimates could be cross-checked with estimates of consumptive use, net of effective rainfall, based on season-wise area under crops in areas irrigated solely from groundwater. The necessary data are available from the quinquennial MI censuses and potentially from remote sensing imagery at the assessment unit level. However, the reliability of these data needs to be verified by first-hand checks at selected locations for valid comparisons.

The MI Census covers only irrigation wells. It does not cover a large number of wells (mostly private) that are used for domestic and other non-agricultural purposes, both in rural and urban areas. Significant volume of groundwater is extracted by public water supply systems (especially in urban areas) and wells owned by industrial establishments. For private wells/tube wells used primarily to meet domestic and non-industrial requirements, we recommend periodic sample surveys to estimate unit draft by direct measurement of the volumes extracted. These surveys should be designed separately for rural and urban areas. The sampling design and measurement protocols have to be decided by the CGWB in collaboration with the SGWBs on the basis of levels of spatial disaggregation needed at the State and National levels.

Water extracted by wells/tube wells operated by the public sector as well as private wells supplying industrial establishments should be measured through metering and be made mandatory for these categories. Estimates of total usage based on this method can be cross checked with estimates of actual consumption for domestic and commercial uses and use by industrial establishments derived from sample surveys of these categories of users suggested later in this report. The desirable density and frequency for monitoring stations in urban areas have to be worked out (for example, at least a few stations in an area of 1 km^2) keeping in mind organizational and cost constraints. These activities should be part of a program for generating data of groundwater balance and utilization for urban areas and SEZs.

4.4.1. Unauthorized extraction

Now let us deal with the issue of use of canal supplies outside the designated command area (i.e. pumping from flowing water in rivers and streams, and underground water from river beds). Some of these (e.g. officially sanctioned lift-irrigation schemes) are probably authorized by the Government, while some others may be captured by the MI Census. But there is reason to believe that much of it is not authorized and goes completely unrecorded. Remote sensing can be used to identify the location of pumping sites along all major rivers and to map the extent of irrigated area outside of but contiguous to major canal commands. This could then be followed by sample field surveys of selected locations to verify whether they are authorized, assess the quantum of water extracted by them, or at least the extent of area irrigated by them. If the extent and seasonal distribution of area irrigated by them is known, the volume of net consumptive use in this area can be estimated with reasonable accuracy. This is a challenging exercise for which we suggest pilot studies of a few select rivers or river stretches be taken up in the XII Plan and extended in the light of their experience.

4.5. Water consumption by end use

Water, be it from rainfall, surface flows and storages, or groundwater, is used by crops, pastures and forests (and trees generally); by households, commercial establishments, and community institutions; mining and manufacturing activities, and for the generation of electricity. The CWC publications give estimates of current consumption and projected requirements of water for various uses. The total volume of surface water utilized in the country for all purposes at the turn of the 20th century is estimated to be around 520 BCM; and the volume of groundwater utilization at 115 BCM. Use of agriculture and livestock is estimated at 540 BCM (85% of the total utilization) and non-agricultural uses for the remaining 15%.

We have already noted that estimates of source-wise use are not based on validated measurements of actual deliveries. Use-wise estimates have even more serious limitations. Even if we can get accurate measures of source-wise use, supplies from each source serve several uses. For instance, it is wrong to assume that total deliveries from surface projects are used only for irrigation. Estimates for non-agricultural uses are based on normative standards of desirable supplies for domestic consumption and patchy data of usage for non-agricultural purposes. Reliable estimates call for systematic surveys of households, non-household commercial establishments, and of industries of various types to determine the actual situation in terms of sources and uses of water, and the disposal of wastewater.

Estimates of future requirements suffer from the same limitations. The demand for irrigation is based on simplistic assumptions regarding the relationship between the output levels of crops and their water needs. Projections for non-agricultural uses are based on norms and patchy data. The basis for projections can be greatly improved once reliable estimates of actual consumption, and the factors affecting their variation, are collected through surveys as suggested above. Even more deficient is our knowledge and understanding of the role of water as a key component of the environmental system, and the impact of natural and man-made changes in the hydrological cycle on riverine and coastal ecosystems. An improved data system for water resources planning and management must expand the scope of, and strengthen the conceptual and empirical basis for, estimating the use of water from different sources and for different purposes.

It is important to note that these magnitudes relate to gross usage which is much larger than the requirements for consumptive use. In the case of irrigated agriculture, the difference is on account of losses in conveyance and distribution, seepage into aquifers, non-consumptive evaporation and sheer wastage. In the case of non-agricultural uses too, the bulk of the volume used ends up as seepage, infiltration or as wasteful evaporation. The focus should be on meeting the requisite important elements of consumptive use. Clearly if the magnitude of leakage and wastage can be reduced – and the scope for it is obviously large – a given magnitude of requirement for consumptive use can be met with smaller gross deliveries. It is therefore very important to understand the factors contributing to inefficient use of water and to device measures to address those that can be contained. Systematic surveys to improve the scope and content of data on consumptive and gross use of water for different purposes are therefore extremely important.

4.6. Agriculture

For all un-irrigated crops (including forests and trees), the quantum of effective rainfall over the area covered by them gives the volume of rainfall available for their use. The total water availability for irrigated areas is the sum of the effective rainfall and supplies from irrigation sources. In both cases, the computation of 'effective rainfall' must take into account local soil conditions, terrain as well as the level and time profile of rainfall. For irrigated areas, the total availability is the sum of the effective rainfall and the volume drawn by the canal systems adjusted for the return flows out of the commands (in the case of surface systems), or the volume of water pumped from underground (in the case of areas irrigated solely by groundwater).

Evapotranspiration rates, which are a function of measurable climatic factors, provide an objective basis for estimation of consumptive use for agriculture. IMD has estimates of potential evapotranspiration rates for the main crop seasons in a 'normal' year for 56 agro-climatic regions of the country. Crop-specific adjustment rates are also available. These adjusted rates applied to the area under different crops in each season and region give a measure of the crop-wise total consumptive use, which can then be aggregated to get the overall consumptive use in agriculture (see Vaidyanathan for estimates of total consumptive use for different regions and basins in the early 70s and late 90s)[5].

However, several refinements are needed to improve the reliability and usefulness of this approach.

[5] Vaidyanathan A (2006) India's Water resources: contemporary Issues on Irrigation, Oxford university press, New Delhi,

1. Available estimates are based on empirical relationship between climatic factors and PET based on the Thornthwait formula. It is desirable to adopt the internationally used Penman recommended by the FAO.

2. Estimates based on empirical formulae need to be validated by comparing them with direct estimates of PET for different regions and basins using standardized and calibrated equipment.

3. Available estimates relate to a 'normal' year. Since both climatic factors and crop patterns vary from year to year, it would be more meaningful to make these estimates on an annual basis for deeper analysis of the relationship between changes in the level and intra-seasonal distribution of PET, soil moisture and crop production.

4. This calls for considerable improvement in the coverage and quality of data both on climatic factors as well as on the extent of irrigated and un-irrigated areas under different crops and in different seasons. Steps to address the former have been spelt out in the section on PET. Those relating to the latter are outlined in the next section.

5. Available estimates of ET relate to field crops of relatively short heights. These may not be applicable to field crops like sugar cane, trees and forests. Appropriate adjustments for these crops are necessary to get reliable estimates of consumptive use by agriculture and forests.

4.7. Non-agricultural uses:

Estimates of the volume of surface and groundwater used for domestic consumption, industries and power generation relate to the country as a whole and that too only for a few years. These are not based on any systematic or comprehensive surveys of actual consumption. Domestic consumption is based on assumptions of desirable levels of water availability to ensure healthy living in rural, urban and metropolitan areas. It is not clear whether these norms are expected to be met by public systems alone or by both public and private systems, and whether they cover usage by commercial, business and community establishments.

The scope and basis of estimates of water consumption by industries and for electricity generation are nowhere spelt out clearly. It is learnt that they are based on rather patchy data on consumption per unit of output in major industries and for large thermal power stations. Nor is there any information on whether the estimate for industries covers all mining and manufacturing, or only organized sector units.

As in the case of agriculture, effective consumptive use for non-agricultural purposes is only a fraction of gross usage. For instance, except for water used for cooking, the bulk of water used for drinking, bathing, washing and in the toilets flows out as wastewater. Much of the water used in industry and power generation also contributes to wastewater flows, which unless treated and recycled, goes into drains and eventually into streams, water bodies and also underground. Very little of the wastewater is untreated and even treated water, which is limited to a few large towns, is seldom recycled.

The growing volume of untreated flow of wastewater into sewers has emerged as the source of increasingly widespread and growing pollution of rivers, surface water bodies and groundwater. The CSE, New Delhi has collected a considerable amount of data to assess the generation and disposition of waste water in a large number of urban centers all over the country. Effective systems to arrest and reverse these trends call for a sensible design that in turn requires comprehensive data on the current situation in terms of the overall water consumption for non-agricultural purposes covering both rural and urban areas, and the generation and disposition of wastewater flows.

The available data to address these tasks are wholly inadequate. The decennial population censuses, National Sample Survey and surveys by Central and State departments responsible for rural and urban water supply give an idea of the rural and urban habitations and populations according to sources of water supply and coverage of public supply systems. But none of them collects any data on the quantum of water use for different purposes and from different sources.

CSE has done a detailed and comprehensive study of public water supply and waste disposal systems of major cities and towns. This study gives an idea of the quantum of water supplied by public systems, but does not cover water from private sources which contribute a significant proportion of total supplies. To date systematic sample surveys of levels, sources and uses of household consumption and their variations across classes have been done only in Chennai and Bangalore.[6] They show that actual consumption met by the overall supply is way below 'norms', and that private sources account for a large part of the supplies. Access to and costs of water vary widely. .

Norms of water use per unit output for a large number of other industries are available with the CPCB, but these are not based on surveys of actual consumption. CSE has also collected data on actual water consumption by select industries which use large quantities of water.

At Central level three agencies namely CWC (for surface water), CGWB (for Ground water) and CPCB (both for surface and ground water) carries out water quality analysis and publishes different reports. Besides many other agencies such as State Pollution Control Boards (SPCB), NEERI etc. also analyse the water samples. Annexure 15 gives some idea of the current status of water quality data. The scope, coverage and reliability of these data need further improvement.

Obviously there are serious gaps in data relating to all nonagricultural uses of water and especially in relation to sources and uses of water as well as generation and use of wastewater by households, commercial establishments and the industries. Filling these gaps must be part of the data improvement program in the XII Plan. The only way to do this is through properly designed sample surveys of different categories of users. Specific suggestions for this purpose are set out later in the report.

---

[6] The findings of the Chennai survey are published in Vaidyanathan A and J Sarvanan, (2004) The Water situation in Chennai, centre for science and Environment , New Delhi. Annexure 16 gives an idea of the design and procedures adopted in this survey

The survey of Bangalore was done in 2009 under the auspices of Argyam, Bangalore

5. IMPACT OF IRRIGATION ON AGRICULTURE

That irrigation increases the productivity of land by facilitating more intensive cropping, changes in crop patterns and raising crop yields is well known. The bulk of the increase in production over the last several decades has come both from expansion of irrigated area and from the rising productivity of irrigated lands. There are frequent references, of a rather general nature, about the reliability of data on the extent of irrigated area, about wasteful use of water, and about yields of irrigated crops being much below potential. But, surprisingly, neither the water resources departments nor departments of agriculture in the Central Government or the States have shown any interest in assaying the available data, much less analysing them to probe these issues. Nor has there been any attempt to investigate the reasons for the large and persistent differences between LUS estimates of irrigated areas and those made by the National Sample Survey and the Planning Commission (see Annexure 17).

5.1. Data on irrigated crop area

The country has an elaborate system for collecting statistics of cultivated area as well as detailed crop-wise and season-wise irrigated and un-irrigated areas at the village level, which is then aggregated and published at the district, State and National levels. The basic data are collected by village revenue officials and supervised by higher level officers. They are supposed to be collected in all villages using a common framework of concepts and procedures applicable to all States.

The reliability of LUS data on irrigated area is adversely affected by ambiguities in the categorization of the sources; biases on account of differential levies of irrigation by different sources and for crops, and failure to record areas irrigated by increasingly widespread illegal and unauthorized lifting of water from canals, river flows and river beds. Data on water releases from major and medium projects as well as crop-wise area irrigated by them are required to be collected for every season and year. There is no mechanism to ensure that these records are scrutinized and verified. The system has been deteriorating for a number of reasons. Dependence on overburdened village officials, replacement of patwaris resident in and familiar with the village by a transferable cadre, and very lax supervision are among the main reasons for the deterioration in the quality of estimates of area and crop-wise yields.

The National Sample Survey provides estimates of irrigated area by source and major crops for different size classes of land holdings at the State and National levels. The concepts and categories used are well-defined and comparable to those used in LUS, though not quite free from ambiguities. While the scope for bias is less, they are prone to non-sampling errors whose magnitude is difficult to assess. The estimates of total cultivated area are considerably smaller than those reported in the LUS, but the proportion of irrigated crop area is higher. The reasons for the apparent underestimation of cultivated land, the definitions of source categories and the basis for determining them from respondents, as well as the experience of investigators on the quality of farmers' response deserve critical scrutiny.

The Planning Commission also provides estimates of irrigation potential and utilization in terms of the total gross irrigated area by surface water (by major/medium and minor projects) and groundwater at the State/basin level. The definitions of potential and utilization, the scope of estimates for surface and groundwater, guidelines regarding the basis on which the States are expected to make the estimates for major and medium projects were all spelt out in a circular dating back to the early 70s (see Annexure 18). It is understood that similar guidelines for minor works (including groundwater) have been issued by the Minor Irrigation Wing of the Ministry of Water Resources. The states report the figures to the Planning Commission at the time of their annual plan discussions. These form the basis of estimates published in plan documents and CWC's water related statistics. The Commission does not have any mechanism to review and verify the reliability of the reported figures.

The persistent divergence between estimates of potential and utilization as reported to the Planning Commission, and between LUS and PC estimates of total and source-wise gross area irrigated arises from differences in definitions, the basis for estimation and the lack of a credible system to ensure that the prescribed protocols are observed in compiling the data at the State level or by the Planning Commission. We strongly recommend that the Planning Commission together with the MoWR constitutes an expert group to undertake a critical review of the extent to which the states in fact observe the guidelines as well as the reliability of the reported data and suggest appropriate changes in guidelines as well as mechanisms (including possible use of sample surveys and remote sensing) for collection and independent validation of data.

5.2. Crop yields

Per hectare yields of major crops are estimated on the basis of supervised harvesting and measurement of production on a statistically selected, crop-specific representative sample of plots by the State Government personnel. These are meant to provide estimates of average yield of each crop within a reasonable margin of error at the State and National levels. For a limited number of major crops, irrigated and un-irrigated plots are sampled separately to provide estimates of yield under irrigated and un-irrigated conditions. The coverage and size of the sample are inadequate to get robust estimates of irrigated crop yields. While the coverage of sample crop-cutting surveys has increased, yield estimates of a number of minor crops (including high-value crops like vegetables and fruits) are still based on assessments by ground-level officials. The quality of data on which yield estimates are made has also deteriorated because of the fragmentation of field work among several agencies done by poorly trained personnel and lax supervision to ensure observance of uniform procedures for sampling and conduct of crop cuts in sampled fields, both of which have been compounded by unwarranted expansion of the number of experiments, much beyond the original design.

A recent expert committee for improvement of agricultural statistics has examined the deficiencies in the current system and underscored the need for its radical restructuring to provide reliable and timely estimates of area and yields[7]. It has recommended the creation of an autonomous and professionally managed National Crop Statistics Centre to put in place and manage a system of sample surveys that would generate reliable and timely estimates of crop-wise irrigated and un-irrigated areas, as wells as irrigated and un-

[7] GOI, Department of Agriculture and Cooperation: Report of the Expert Committee on Agricultural Statistics, 2011 (available on the website of the Department's Directorate of Economics and Statistics).

irrigated yields of major crops within a reasonable margin of error at the State and National levels. The sampling design envisages stratification by agro-climatic regions and within each such region of villages according to the level and nature of irrigation. The number of sample villages that need to be covered for this purpose will be a fraction of the 120,000 villages sought to be covered under the existing system. It also provides for validation of primary data through an independent set of inspectors in a sub-sample of villages and plots. Furthermore, it is envisaged that independent estimates of the total crop area and area under major crops in the sample villages will be made using remote sensing. These reforms are under active consideration of the Government.

5.3. Assessing water use efficiency

Water use efficiency in agriculture has two components: (1) the ratio of effective, or consumptive, water use per unit of crop area as a proportion of the total average water supply per unit of crop area, and (2) the value of output per unit of crop area per unit of its effective or consumptive use of water. The former is a measure of the technical efficiency of water use and the latter a measure of the productive efficiency.

5.4. Technical efficiency

Crops get water from rainfall and supplies from irrigation sources. For un-irrigated crops rainfall is the only source of water.

The usual working assumption that the contribution of rainfall to soil moisture in cropped area is equal to 80% of the local precipitation is an approximation. The relation between rainfall and soil moisture build-up under rainfed conditions is quite complex and apt to vary depending on several factors, which calls for systematic investigation in different agro-climatic regimes.

In irrigated areas, a considerable amount of water drawn from the source is lost before it becomes available to crops which are being irrigated. Losses occur partly due to evaporation and seepage in the distribution network and on the field, and partly due to weaknesses and breakages in the conveyance channels, and excessive use of water. Engineers adopt working assumptions, at the time of designing the system. The CWC has initiated a program for systematic assessment of these losses and the factors that cause them, mainly to help in planning corrective measures to contain the losses to a minimum. But the overall technical efficiency of water use can be estimated even without these data because consumptive use of crops can be estimated directly on the basis of water used by crops through evapotranspiration.

IMD has estimates of ET, by agro-climatic regions and seasons, based on empirical formulae and detailed data on irrigated areas. Based on these the actual total consumptive use of irrigated crops can be estimated. Deducting the contribution of rainfall (assumed to be 80% of total precipitation) gives an estimate of contribution of irrigation to consumptive use. The ratio of consumptive use of irrigation water (PET – effective rainfall) to gross volume of water supplied is a measure of the technical efficiency of use of irrigation water. Using this approach and available data on all the above variables, a recent study estimates the technical efficiency of water use in groups of major basins at between 35% and 55%.

A similar exercise based on data on rainfall and season-wise gross deliveries for some 140 projects (Annexure 13), cropped area and Evaporation rates (see Table 9) shows that in over 60% of the commands the total rainfall is greater than PET on an annual basis; and in about 40% of the commands during rabi and summer. Of the remainder, gross volumes of water reported to be supplied to the systems exceed the deficit of rainfall relative to PET, which gives a measure of irrigation water needed to meet the consumptive use requirements of crops grown in their commands. In this group, the technical efficiency [(PET- rainfall)/gross irrigation supplies] is as low as 10% or less in about a fifth of the systems, and less than 40% in nearly 60 of them. Of the 80 systems in whose commands the rainfall is short of PET during Rabi and summer seasons, the technical efficiency ratio is less than 40% in 31 and less than 60% in 69. The quality of data and the assumptions underlying consumptive use are admittedly gross and leave much room for critical scrutiny. But they do indicate the low level of efficiency at which water from the surface system is being utilized.

Table9 Frequency distribution of technical efficiency for selected projects

(PET –RF) / GIS * 100	Number of projects	
	All seasons	Rabi/summer
Negative	22	1
0	65	58
1–10	11	3
10–30	14	9
30–40	9	19
40–50	4	23
50–60	4	15
>60–70	8	9
All	137	137

-

1. For details see Vaidyanathan, 2006, op.cit

-

These are based on available data and assumptions regarding the quantum of water use, total and crop-wise area irrigated and PET. All of these leave much room for improvement. The scope and reliability of these estimates can be greatly increased once our recommendations for improving the quality of the basic data are implemented. .

Such refinements are possible by:

(a) Computing norms of consumptive use using the actual values of PET and rainfall observed in the selected periods. This is possible using the daily weather observations that are made available by IMD.

(b) A systematic compilation of data on the distribution of area under different crops/varieties according to sowing and harvesting dates. The cost of cultivation surveys are a rich source of data on sowing and harvesting dates by crop and region, and under irrigated and rainfed conditions as well as the changes in these over time.

(c) Making an independent and objective estimate of irrigated and un-irrigated areas under different crops or, as a next best alternative, of the extent of green cover at different points of time in each season. Satellite imageries, which are available for at least the last 30 years, can be used to compile independent estimates of irrigated and rainfed crop areas in different seasons at different points of time.

5.5. Productive efficiency

Irrigation increases production per unit area of land by increasing cropping intensity, changes in crop pattern and raising yields of individual crops. The Planning Commission funded several research studies to assess the impact of irrigation on agricultural productivity in the command areas of selected projects during the fifties and sixties, but very little thereafter. Numerous survey-based studies on different aspects of irrigation have been done and are being sponsored by ICAR, ICSSR and other organizations. Not all of them are published. However, their usefulness is limited because of great variability in their scope, focus and quality, with few repeat surveys to track the performance of particular systems over time.

Official statistics provides quite detailed data on land use, and crop wise irrigated and un-irrigated areas. Estimates of yield of irrigated and un-irrigated areas based on sample crop-cutting surveys are available for major irrigated crops. IMD has estimates of ET in a normal year for different agro-climatic regions. These can be used to estimate overall output per unit of irrigated and rainfed areas and per unit of consumptive use at the State and district levels. They show wide differences in all dimensions across sources and agro-climatic regions, and also suggest that, contrary to expectation, productivity per unit of consumptive use under irrigation is not always and significantly higher than that of rainfed crops (Vaidyanathan 2006, op.cit). But given the limitations of official data, and the fact that they involve a number of assumptions, these estimates need to be interpreted with caution. These limitations can be addressed and the estimates of productivity impact can be refined as the quality of official agricultural statistics improves.

If this proposed restructuring of the agricultural statistics system and suggestions for generating refined season-wise PET estimates every year are properly implemented, we will have far more reliable and validated estimates of area and yield for all major irrigated and rainfed crops at the State level. It would then be possible to track the overall performance of irrigated and rainfed agriculture in terms of crop yields and productivity per unit of consumptive water use across different States and over time.

6. TRACKING PERFORMANCE OF IRRIGATION SYSTEMS

Rapid expansion in the use of surface and groundwater has helped meet the growing demand for water for domestic consumption, agricultural and non-agricultural uses. But despite expansion in aggregate volumes, vast sections of the population still do not have access to adequate supplies of safe water for domestic use. The impact of irrigation on agricultural growth is far less than that expected, and much below potential. There are palpable signs of wasteful use of water, of overexploitation of groundwater, and of increasingly widespread pollution of water sources. Conflicts over water are growing. Altogether the country faces a serious water crisis. The nature, severity and causes of the crisis cannot be understood without an objective and comprehensive assessment of the current situation in terms of the utilization of water from different sources and for different purposes, incidence of avoidable waste, and efficiency in the use of water. The available data are quite inadequate for making such an assessment.

During the 1950s and 1960s, studies of several specific major and minor projects were made by the Program Evaluation Organization and the Committee on Plan Projects of the Planning Commission. Though few in numbers, they provided valuable information, analysis and insights into the reasons for wide divergence between the designed and actual extent of irrigated areas and crop patterns. Unfortunately these were not sustained. The Planning Commission, as well as other Government institutions (UGC and ICSSR) also sponsored surveys of specific projects (mostly large-scale canal systems) to assess the impact of irrigation on crop patterns and the overall productivity across different segments of the command area, and of users[8].

With a few exceptions, their approach was to survey a sample of cultivators in particular systems and compare the pre- and post-project situations at a single point of time. Some, but very few, have surveyed the performance of specific systems over time. Their scope, design, quality and timing are far too varied to permit any meaningful comparisons across systems, or of the overall impact of these projects on land use, cropping and production. The interest of both funding agencies and researchers towards these studies has dwindled over time.

More recent times have witnessed extensive research on characteristics of and trends in irrigation using groundwater, its impact on agricultural production and productivity, inequalities in the access to this resource, emergence and functioning of water markets, and widespread and increasing overexploitation. They have triggered widespread debates on the contribution of groundwater to agricultural growth, socio-economic impact of the way groundwater is exploited and used, factors responsible for its depletion, and legal, institutional and policy measures to arrest and reverse these trends. There are few rigorous assessments of the magnitude of groundwater extraction in the study areas as well as of sustainable levels of overall extraction, and the rate at which they are being actually extracted.

Also noteworthy is the fact that there are few objective evaluations of the physical works and institutional reforms that were planned under major program initiatives to improve the performance of major and medium works (such as the Command Area Development, the National Water Management Project, Promotion of User Participation in Water Management and the Accelerated Irrigation Benefit Program). There have been no evaluation studies of their impact on agricultural productivity and the efficiency of water use.

---

[8] A selected list of these studies is available in Vaidyanathan, A (1999) Water Resource Management: Institutions and Irrigation Development.in India, Oxford University Press, New Delhi

Devising strategies for more efficient, equitable and sustainable use of water resources calls for detailed information based on tracking of trends in land and water use, crop patterns and crop yields of irrigated and rainfed crops in different regions and through different ways of augmenting and managing water. For this purpose it is necessary to track the performance of specific irrigation systems in terms of volume of water supplied, efficiency of use, and productivity per unit of land as well as per unit of water, distribution of benefits across different socio-economic groups, and environmental impact. It is also important to examine the divergence between the assumptions underpinning the original design and other factors (including changes in the organization and management of systems) subsequently found to be consequential. Such studies have to be designed keeping in view the different ways in which agriculture gets water (large surface systems, groundwater, small-scale surface works, and areas solely dependent on rainfall) and the vast diversity of agro climatic conditions.

Though the number of works (over 6000 major and medium surface water projects, 30 million wells and over half a million minor surface irrigation works) is huge, properly designed and structured sample surveys of systems in each category representative of different types, sizes and regions can provide reliable data for assessing the performance of irrigation systems and also the impact of various interventions for improvement of physical facilities and institutional arrangements. The scale of such surveys, their logistics and costs can be brought within manageable limits using techniques of stratified sampling (or typologies). Specific suggestions for surveys of different types of systems are outlined below.

6.1. Major and medium surface water projects

There are some 6000 systems in this category. Details of their physical facilities, operational rules and procedures, inflows and withdrawal of water as per approved design must be available with the CWC (whose clearance is necessary in most cases). Records of the actual current position in these respects, as well as crop-wise areas irrigated by them, are supposed to be maintained by the officials operating these systems. The CWC should be enabled to collate, digitize and archive as much of these data as possible. The Planning Commission should take a proactive initiative to persuade the States to cooperate in providing the operational data to the CWC which, under the Constitution, is responsible for ensuring efficient and sustainable management of the country's water resources. To begin with, this exercise should cover the 81 large projects that are estimated to account for 60% of the country's total storage capacity and a sample (or perhaps 200) of the rest stratified by size and their share in total capacity.

Among these, projects which together cover a substantial proportion of water utilized in each of the major river basins should be selected for detailed survey. The selection should cover a significant number of the large projects and a smaller fraction of the rest depending on their size. The survey should provide data on: (a) the actual condition of the different components of physical infrastructure of the system and their deficiencies based on first-hand field inspection; (b) verified measurements of inflows into and discharges from the reservoir/barrage into the canal network and into the river over a year, and their accuracy; (c) the area actually irrigated within the command and also in its contiguous areas that seem to be using the canal water directly or indirectly; (d) the number of wells/tube wells in these areas and the volume of water extracted and used from them, and

(e) inputs and outputs of crops cultivated in a sample of plots by interviewing farmers who cultivate them.

6.2. Wells and tube wells

Minor irrigation surveys have generated a wealth of disaggregated data on the characteristics and spatial distribution of wells/tube wells, and the area irrigated by them. They also distinguish between wells/tube wells that are the sole source of irrigation and those used conjunctively with surface sources. Based on this information, districts (and villages within each district) can be classified according to the density of the wells and extent of area irrigated; this will provide the basis for rigorous stratified sampling of districts/villages within each basin for estimating overall groundwater extraction and use at the basin level within a reasonable margin of error. Surveys of wells used conjunctively should be covered as part of the study of surface systems and the stand-alone wells through a separate survey (see Annexure 14).

The purpose of these surveys, besides being useful for verifying the accuracy of the census data, is to obtain more detailed data on the current depths of the water table and water columns in the wells and their seasonal variations; the duration of their operation during different seasons and the volume of water that is extracted; the extent of crop-wise area irrigated; the prevalence, incidence and terms of trade in water at present; costs of extraction and distribution, and access to different classes of users. Along with data on the current situation, it should also generate data to get an idea about the trajectory of past growth in different categories of wells, lifting devices and changes in the depth of wells, as well as the characteristics of wells that have gone out of use and the underlying reasons. Data from such a survey will also help improve our understanding of the characteristics of aquifers in different regions and the extent to which the groundwater levels and the seasonal profiles of wells/tube wells in use obtained from these surveys correspond to those of the observation wells of the CGWB and SGWBs .

Many of these specific aspects have been the subject of several researches in different parts of the country. But because of differences in scope, focus and methods, it is difficult to piece together a coherent overall picture. The proposed surveys can and should be designed to get such a picture. Scientists and technical staff at the existing institutions who have experience and competence in research and sample surveys on water-related issues are a valuable resource to be mobilized for this purpose. The most challenging task in this effort is to find workable and affordable ways of measuring and estimating the volume of groundwater being extracted and the potential thereof.

6.3. Small surface water systems

A great deal of information on their characteristics and location, and the area irrigated by them is available from the Minor Irrigation Census. Detailed State and district-level tabulations are available, but there is little sign of these data being used by the State Governments, or for that matter by researchers, for designing strategies and priorities for expansion and modernization of these sources. Despite widespread complaints about the physical deterioration of minor works, reduction of their capacity and large numbers going out of use, the States have shown very little interest in assessing the extent of their degradation and examining the causative factors[9]. The structure and functioning of institutional arrangements for the management of these community works have attracted considerable attention of the researchers[10]. Systematic studies of the evolution and current conditions of this category of work covering their physical condition, water use, cropping patterns and yields, and institutional arrangements for their sustenance are relatively rare[11].

Although these systems account for only a small fraction of the water resources mobilized and used by large surface projects and groundwater, their role in harnessing rainfall in local tanks and ponds and in recharging local groundwater sources is far higher in proportion. They serve a critical role in meeting basic human needs, agriculture and animal husbandry in several hundreds of thousands of villages. These minor works are also important for another reason. Most of them have been built and are sustained by local communities and in many cases continue to do so against great odds. Even in the case of large Government controlled tanks, informal community institutions play a significant, though variable, role in the maintenance of facilities and regulation of water distribution. Better understanding of these institutions and their functioning is important both because they are an intimate part of the community assets, and because they are more likely to be better managed and sustained by self-enlightened community perceptions and initiatives – a endeavour that has the potential to be greatly enriched by systematic knowledge, not currently available, of their seasonal and long-term behavior.

There is widespread impression that a large proportion of these systems has been severely damaged or become derelict due to neglect, and that an increasing number is falling into disuse due to encroachment and being used as dumping ground for wastes. Official statistics in fact shows a progressive decline in the area irrigated by these sources. Some recent surveys in Tamil Nadu do not corroborate these tendencies, at least in the case of the relatively large tanks under direct control of the Government. Furthermore, there is considerable evidence that large outlays of public funds on programs for repair and modernization of these works have not made much of an impact. There is hardly any study of the conditions of the much larger number of small tanks and even more numerous local ponds that do not figure in the official statistics. Official water resources departments have shown little interest in such studies, despite the demonstrated capability of remote sensing as a technique for accurate monitoring of these works.

Though these works are vast in number and heterogeneous in character, they show distinct regional concentrations and patterns. Again, the MI Census gives a wealth of material that helps identify regions with significant density of different types of works and design sample surveys to provide a reliable picture of the conditions and trends in different regions. Annexure 19 gives an idea of the design and scope of surveys that have been used to study the technical, institutional and socio economic aspects of tank systems in Tamil Nadu. These will need to be modified and adapted to cover surface lift and diversion works, and small ponds in other parts of the country.

[9] Remote sensing can be used to good effect for preparing an accurate inventory of all tanks (including relatively small ponds) and provide an objective basis for verifying these claims and checking ground reality against official records. But there has been little interest in exploiting this potential despite it being demonstrated in a few cases (e.g. an NRSA study of Kolar district).

[10] There are numerous theoretical and empirical studies on this aspect both in India and worldwide. For a select bibliography of these studies see Vaidyanathan, 1999, op cit.

[11] See, for example, studies of tanks and tank systems in the Palar and Periar Vaigai basins of Tamil Nadu.

6.4. Water sheds

A particularly glaring gap in data relates to watersheds. The Ministry of Water Resources has shown scant interest in them, with these being outside their domain. Perhaps also because their contribution to augmenting utilizable water resources is negligible compared to that of irrigation. While this may be largely true, fuller and more effective use of local rainfall can add significantly to augmenting water supplies and raising productivity of rainfed lands (which after all account for the major part of total cultivated area) as also for domestic and other non-agricultural uses . Watershed development is an important component of the Five Year Plans. But these programs are widely known to be poorly planned and implemented.

Detailed mapping of land and local water resources potential and works for control of soil erosion and more effective harnessing of local rainfall at the level of micro watersheds is reported to have been done through remote sensing. The scope and content of data generated by these maps, and the extent to which they are available and actually used in planning watershed projects need to be documented. More important is the assessment based on actual and continuing monitoring of the resultant augmentation of water supplies and their impact on biomass production and sustenance. Studies to address these issues must be an integral part of the program to improve the database for water resources development and management.

The purpose of the suggested surveys of different types of irrigation works, rainfed watersheds as well as those relating to domestic and non-agricultural uses of water is to fill in large gaps on all these respects. They are meant to provide comprehensive data on all important technical and operational aspects of water utilization and impact from different types of projects in different regions and river basins. The programs to be undertaken in the XII Plan should provide a benchmark of the current situation, against which changes over time are to be tracked through periodic resurveys of the same projects and locations.

All this adds up to a challenging and demanding task of an unprecedented scope, scale and organizational effort. We are not in position to assess the financial outlays. required for the proposed surveys. The aim should be to get a reasonably accurate picture of the current situation in major river basins/agro climatic regions/ states. The scale can be made manageable by Imaginative use of statistical sampling techniques. We are not in a position to assess what that scale would be and what it would cost. These can be decided only after the sampling strategy and survey design are worked out by experts. We also need to provide for funding of academic and research institutions outside Government to conduct analytical research on the data that that will be generated by these surveys and by programs for improvement in basic technical data. We suggest that the XII Plan provide an allocation of Rs 500 crore for in-depth sample surveys of major and medium irrigation projects; minor surface works, groundwater exploitation and use, and nonagricultural uses and for analytical research.

It should be viewed as National effort of the Centre and the States, with the Central Government taking the lead in creating appropriate institutional arrangements to ensure independent and professional conduct of the surveys. They fall within the domain of different executive ministries at the Centre (Ministries of Water Resources, Agriculture, Water Supply and Rural Development) and require active cooperation of the State Governments. They call for knowledge and expertise of different disciplines: hydrologists, hydro geologists, irrigation engineers, economists, statisticians and survey techniques. We suggest the constitution of a Steering Group chaired by the Deputy Chairperson of the Planning Commission (or the member in charge of water resources) to work out the modalities of organization and funding in consultation with the concerned ministries and agencies of the Central Government and the States.

7. IMPLEMENTING THE PROGRAM

Our review has highlighted significant inadequacies in the scope, level of detail and reliability of data currently available on practically all important aspects of water resources, their potential, utilization and impact. We have spelt out in some detail the improvements needed to address these deficiencies with a view to building a comprehensive database on all these aspects that will provide better factual and analytical basis for decision-making by planners and policy-makers, facilitate research by academics and professionals outside of the Government and help promote a more open and informed discussion of issues involved in the public forum.

This is possible only if the highest levels of the Planning Commission and agencies responsible for water resources development: (a) recognize the serious lacunae in the database for deciding strategy, programs and policy to ensure efficient, equitable and sustainable use of this critical natural resource, and (b) are willing to implement programs necessary to build, progressively, a more comprehensive and reliable database and back them with commitments to provide the necessary financial and human resources. The XII Plan should mark the beginning of a strong and determined effort in this direction. We suggest the constitution of a Steering Group chaired by the Deputy Chairperson of the Planning Commission (or the member in charge of water resources) to address these issues and work out the modalities of organization and funding in consultation with the concerned agencies of the Central Government and the States as well as non-Governmental experts from academia and research institutions.

Data improvement should be viewed as a National effort of the Centre and the States, with the Central Government taking the lead in creating appropriate institutional arrangements to ensure independent and professional conduct of the surveys. In absolute terms, the financial outlay needed for implementing the suggested program is around Rs 8050 crore. At present this can only be an indicative figure subject to scrutiny of details of individual components as they are worked out. This may seem large. But it must be remembered that we do not have comprehensive, comparable data on investments in data improvement for earlier plans. Substantial increases are in any case necessary to correct the gross neglect of data improvement in the past.

A significant part of the suggested activities can be implemented by reordering extant practices of data generation, archival and dissemination by equipping the existing personnel with knowledge and understanding illuminated by modern developments in instrumentation, computer and information systems. Moreover, it is appropriate to view the proposed outlay in relation to the scale of total outlay on water-sector programs, which is more than Rs 200,000 crore in the 11th Plan and may well be double that in the XII Plan. The suggested outlay on data improvement which will amount to barely 4% of this total must be viewed as an investment in knowledge based on objective data and analysis of high professional standard, which is critical to more efficient and sustainable programs for water resources.

The real challenge is not so much finance as in devising effective institutional arrangements and ensuring trained personnel to implement the programs. This calls for the creation of effective mechanisms for: (a) articulating a common framework of scope, concepts, and instrumentalities for collection and collation of data on different aspects of water and laying down procedures and protocols to be followed by all agencies that collect the various water-related data; to facilitate building a comprehensive, internally coherent and comparable database on water resources, and ensuring that they are in fact observed; (b) determining the role of different agencies – Government and non-Governmental – in collecting data on different themes identified in the report; (c) designing the scope, priorities, selection of locations, instrumentation/survey design, personnel requirements, organization and supervision of field work in each major theme, and (d) collating the data on all aspects and organizing them in a common digitized platform that permits them to be accessed readily in the desired level of detail at the regional, State and National levels. They call for increase in the number and quality of professional personnel and technicians at all levels.

It is useful to distinguish between measures for: (a) improving the scope and content of basic meteorological, hydrological and geophysical data relevant for estimation of surface and ground water resources potential and their utilization; (b) the program of sample surveys to fill in gaps in data on water utilization by source and use, and for assessing the impact of irrigation on agriculture, and (c) making the data in a form and through means that are easily accessible to both Government agencies, interested researchers and the public.

7.1. Water resources potential and utilization

The former involves a major expansion and improvement of the physical infrastructure through investments in specialized equipment using up to date technology. These should be funded by the Centre. Central nodal agencies (IMD, CWC and CGWB) need to rework protocols for collection, recording and archiving data with improved technology. This aspect has to be taken care of by the nodal agencies. In doing so, it is important to ensure that they work in close collaboration while addressing the following tasks:

(a) Articulating a common framework of scope, concepts, and instrumentalities for collection and collation of data on different aspects of water and laying down procedures and protocols to be followed by all agencies that collect the data; to facilitate building a comprehensive, internally coherent and comparable database on water resources, and ensuring that they are in fact observed;

(b) Determining the role of different agencies – Government and non-Government – in collecting data on different themes identified in the report.

(c) Designing the scope, priorities, selection of locations, instrumentation/survey design, personnel requirements, organization and supervision of field work in each major theme.

(d) Collating the data on all aspects and organizing them in a common digitized platform that permits them to be accessed readily in the desired level of detail at the regional, State and National levels. In addressing these issues, it is useful to distinguish data needed for assessment of water resources potential and use from those that seek to track the performance and impact of different kinds of water-control projects across regions and over time.

Effective collaboration and coordination between different Governments agencies involved in the collection of data is essential. The actual collection of data will continue, as at present, to be handled for the most part by state Government agencies. Substantial amount of data are also being collected by non-Governmental organizations. We have already pointed out that the states have been reluctant to cooperate with the Central Government agencies in ensuring observance of the prescribed protocols and procedures for collection and validation of data, verifying their accuracy and transmitting all the data to a central pool. In order to address this problem, a serious effort needs to be made to persuade the States that with water being a critical natural resource and one which is facing a crisis, the Centre has the responsibility to ensure its equitable, efficient and sustainable utilization in the larger National interest. And that access to comprehensive, reliable and validated data is essential for this purpose.

At the same time the Central Government should assert its authority under law over the states to maintain the required data in prescribed form supply them to the Central Government and verify their accuracy[12]. In order to incentivize the States to cooperate, the Centre could undertake to meet all or a large part of the cost of installing equipment, additional staff to be employed and training programs to upgrade their skills conditional on their entering into a formal compact to provide access to the required data. Another possibility is to get the states to agree to install telemetry devices in selected key locations and projects, so that measurements can be automatically transmitted to the central data pool.

Ensuring adequate number of trained staff is the other important requirement. Inadequate and poorly trained manpower at the ground level is a major problem even now.

---

[12] The Amended Inter-State Water Dispute Act, 1956 regarding 'maintenance of data bank and information' provides that:

1) The Central Government shall maintain a data bank and information system at the National level for each river basin which shall include data regarding water resources, land, agriculture, and matters relating thereto, as the Central Government may prescribe from time to time. The State Government shall supply the data to the Central Government or to an agency appointed by the Central Government for the purpose, as and when required.
2) The Central Government shall have powers to verify the data supplied by the State Government, and appoint any person or persons for the purpose and take such measures as it may consider necessary. The person or persons so appointed shall have the powers to summon such records and information from the concerned State Government as are considered necessary to discharge their functions under this section.

In pursuance to the above, the Ministry of Water Resources vide Gazette notification dated 23rd November, 2005 has appointed the CWC as the agency for maintaining the databank and information system for each river basin, which shall include data regarding water resources, land, agriculture and matters relating thereto in such form and manner as may be required from time to time by the CWC to be made available by the respective State Governments. Further follow-up action is reported as being taken by the Water Resources Information System Dte, Information System Organization, CWC, but with little effect.

Agencies at all levels tend to deploy poorly skilled, untrained in the use of modern instrumentation and often unwilling engineers/technicians for such jobs. Shortage of staff, and in particular of adequately trained staff, combined with the lack of a well-equipped facility for testing, calibration and repair of such field instruments is recognized as an important reason for the limited impact of earlier projects (such as the Hydrology Project) that introduced modern instruments.

Effective use of more sophisticated instrumentation on the scale proposed in the report will be even more demanding in terms of both the needed increase in the number of staff at all levels and of the higher order of training and skill than is currently available. It is therefore necessary that central nodal agencies should assess the requirements of professional and trained personnel at various levels to maintain and operate the system, and suggest a concrete program for organizing training facilities to meet these requirements. The suggestion to establish a nodal agency, along the lines of HIF of the US Geological Survey – for supply, quality testing, repair and maintenance of instrumentation requirements of all relevant organizations also deserves serious consideration.

7.2. Surveys of selected systems

We have emphasized the need for a major restructuring of the present system of collecting data on land use, crop areas and crop yields along the lines suggested in a recent report of an expert committee constituted by the Ministry of Agriculture and cooperation. Under this arrangement – which is under active consideration of the Ministry – area and yield of irrigated and rainfed crops will be estimated on the basis of sample surveys to be designed and supervised by an autonomous, professionally managed authority at the Centre. Field data collection in sampled villages and plots will be done by dedicated staff of the State statistical bureaus funded by the center, based on sampling design, and procedures for field data collection prescribed by the Central authority and validated by its inspectors. Better data on these aspects, and those relating to the volume of gross water use and consumptive use by crops, will make possible more reliable assessments of technical and productive efficiency of water use in agriculture, but only at the State and agro-climatic regional levels.

In addition, we have suggested surveys to provide: (a) comprehensive data on all important technical and operational aspects of water utilization and impact from different types of projects, and (b) consumption of water for non-agricultural purposes in different regions and river basins. They are meant to provide a benchmark of the current situation, against which changes over time are to be tracked through periodic resurveys of the same projects and locations. The survey themes fall within the domain of different executive ministries at the Centre (Ministries of Water Resources, Agriculture, Water Supply and Rural Development). They call for knowledge and expertise of different disciplines: hydrologists, hydro geologists, irrigation engineers, economists, statisticians and survey techniques.

They should be planned as a National effort with the Central Government taking the lead in providing adequate and assured funding for these surveys and creating appropriate institutional arrangements to ensure independent and professional conduct of the surveys. We suggest the constitution of a steering committee chaired by the Deputy Chairperson of the Planning Commission (or the member in charge of water resources) to work out the modalities of organization and funding in consultation with the concerned ministries and agencies of the Central Government and the States.

This Committee could then constitute sub-groups comprising professionals from concerned departments/directorates and non-official experts in relevant disciplines to work out the scale, scope, objectives, design and field procedures, and validation that should be observed by all institutions selected to conduct the studies in each theme.

For each of these surveys the scope, objectives, design and field procedures and validation must be the same for all basins and regions to be worked out by sub groups of the Steering Committee comprising official and non-official experts in the relevant disciplines. This Committee should work out the details of criteria and procedures for stratification as well as selection of survey locations and of sample observation points/respondents within each, and decide on the size of the sample that balances the need to get reliable basin-wise estimates, and costs on a manageable scale. They should also be responsible to prepare, in consultation with experts in sample survey techniques, and after pilot testing in the field, the questionnaire and procedures to be followed in getting the data, and the allocation of responsibilities among different experts.

The actual surveys will have to entrust to Government and non-Governmental research institutions with interest and experience in such research. It is important to have an institutional arrangement for the proper conduct of these surveys through a network of research institutions using well defined common concepts and methodologies to ensure comparability across regions and over time. In order to track trends over time, the surveys of selected projects/regions should be repeated periodically.

The identification of official agencies and non-Governmental research institutions for undertaking field work, the criteria for screening and selection among them and the MOUs laying out the terms and conditions of the contract with them, and the arrangements for supervision and inspection of field work should also be vested with the Steering Committee or its sub groups. Needless to say, the composition of the Committee and its sub groups and careful selection of members to ensure high professional standards, and a strong secretariat for keeping track of the progress of field work and to ensure its proper supervision are critical to the success of this endeavour.

The model that is worth serious consideration is the one followed successfully by the National Family Health Survey (NFHS) in three successive periods. NFHS has a National Steering Committee of experts, which works out the common framework for surveys, identifies institutions for conducting the actual field work, and participates in processing the data and preparing the reports of the main findings, leaving ample room for more detailed analyses of the data by individual researchers. This arrangement would help create and nurture an interactive and collaborative research network for sustained research on water-related issues.

7.3. Importance of research

Our recommendations, if implemented, would generate far more data of wider scope, greater reliability and detail than are currently available. The adoption of uniform concepts, definitions, and data collection and validation procedures makes for greater comparability across space – time than is possible under the existing system. The proposed system will provide a more objective and reliable empirical basis for: (a) monitoring of the current situation and emerging trends in various aspects of climate, availability and use of water from different sources and for different uses, and their impact on agriculture; (b) a firmer basis for the assessment of water resources potential from different sources in different basins and sub-basins down to watersheds; (c) estimation of availability of surface water and groundwater in specific locations and parameters (like degree of dependability, crop water requirements, conveyance and distribution losses) needed for project design; (d) more efficient management of water at the project level, and (e) formulating overall strategies and polices for addressing current crises arising from scarcity and conflicts over water and its misuse and over- exploitation, and for ensuring that future developments are consistent with the imperative of equitable, efficient and sustainable use of this critical resource.

Exploiting this potential however requires a great deal of analytical work both in Government agencies responsible for planning, policy-making and implementation, and in universities and research institutions. At present much of data-based research is limited to Government departments that collect the data. IMD uses its data to improve short and medium-term weather forecasts, explore long-term changes in the levels and patterns of precipitation in different regions, and as inputs to studies on climate change. Met data are also used by the CWC and CGWB, along with data collected by them and their State counterparts, for assessments of surface and groundwater resources and for the design of specific projects. But the range of issues they address, and the research they sponsor from other institutions, are limited to assessment of resource potential and utilization, and project design. This is due to a combination of data inadequacies, difficulties of data-sharing across agencies, and weak in-house capacity for analytical research. But the more important reason is that lack of data-based analyses and research as key inputs for operational purposes and for planning and policy, is particularly marked in the water sector.

Agencies concerned with water resources development must make a conscious effort to use objective data based analysis as essential inputs in decision making and develop in house skills and capacity to provide such inputs. Aspects that transcend the domain and expertise of particular departments – and these are many – call for collaborative studies with experts from different agencies at the Centre and the States concerned with water. We have made a number of specific suggestions on this aspect:

- Estimating rainfall- infiltration rates, conveyance and distribution losses under irrigation in different agro-climatic regions.

- Soil moisture model for estimating crop evapotranspiration and run off.

- Evaluation of evapotranspiration and crop coefficient values used for estimating irrigation requirements for different field crops and trees under different agro climatic conditions.

- Consumptive use, seasonal evapotranspiration and water use efficiency for crops in India.

- Assessing impact of agricultural drought on dry land crops using water balance technique.

- Estimation of water balance at different levels ranging from micro watersheds to river basins.

- Models to integrate information on water availability with on-field soil moisture balance for better water management.

- Past trends in PET over India and projected estimate under climate change.

- Study of climatic water balance for crop planning.

- Interdisciplinary research project focusing on select centers to explore their use in both back casting and forecasting crop yields would be a creative initiative.

These are illustrative of the kinds of research that are relevant for operational decisions to be made by executive agencies in the Government. Not all of it can be handled by their in house units. Moreover there are many other aspects that call for rigorous scientific studies to deepen our understanding of the factors and forces that shape these aspects and their dynamics. Such as, for example, interactions between climate, water requirements, agricultural technology and crop yields; their long term impact on soil structure, water quality and environment; assessing the rationale for and consequences of proposals for augmenting utilizable water resources through groundwater recharge and inter basin transfers, and predicting the probability of timing, nature and magnitude of climate change, and its impact on water supply and demand. Most of them have to use knowledge and insights from several disciplines in a creative way. This is possible only by involving academic and research institutions with expertise in different disciplines in conducting collaborative and interactive studies[13]. A proactive policy is necessary to facilitate, encourage and support this on a far bigger scale and in a better planned manner than at present.

This can be done in several ways:

1. Commission experts from research institutions as consultants to provide analysis and advice on technical aspects relating to the design of particular projects or problems relating to particular regions.

2. Sponsor similar research projects but of broader scope and focusing on a class of problems of interest to each agency.

3. In select areas that call for a multi-disciplinary approach, undertake collaborative projects with other Government agencies and with participation from invited outside experts.

[13] In this context it is worth noting that IMD had pioneered a program of field research on crop – weather relations in several locations, which was conceived and implemented in this fashion. Though this was abandoned, the Department can draw on that experience to revive the approach and work in close collaboration with researchers on agriculture, water and climate sciences from within the Government and these in Government and academic institutions.

4. Prepare a program of research on selected themes, invite proposals from interested researchers/institutions, and select projects to be funded based on an independent review process.

5. Give liberal access to all available data on all aspects to interested researchers, leaving them free to explore themes/issues of their interest.

Given the wide range of issues to be covered and the importance of research with assured funding on an adequate scale and continued funding, we strongly recommend that the Planning Commission take the lead in constituting a National Advisory Committee comprising heads of selected key agencies responsible for water resources development and eminent scientists and experts from water-related disciplines. This will give a strong signal about the importance that the Government attaches to promoting high-quality professional research on water as the basis for policy and its commitment to encourage and support it with assured and adequate funding. It will also provide a forum for a collective effort to identify and prioritize research themes/problems, and a framework for individual agencies to decide their programs.

7.4. Issues relating to access and use

In order to facilitate research, it is important to ensure that all primary data collected by field agencies of all departments be digitized and transmitted to a pool at the State and National levels. Collation at the higher levels has to be selective and less detailed in terms of spatial and time coverage. But they should form part of an integrated and interlinked system which permits details to be accessed at all levels. While individual agencies may have their own computerized data networks, the data collected by all agencies need to be brought into a comprehensive National database.

To be effective, such a platform must ideally meet the following criteria:

1. Objectivity.

- The data (irrespective of the parameter used) must be such that they are not subject to external dependencies; and cannot be empirical or intuitional entities. The technical theory and process in support of the measurement process should be sound.
- For components of the database that are empirical or notional, the due justification will have to be available. This justification will have to be such that it stands the test of time and of multiple users.
- Any objective data will automatically stand the test of integrity and time-tested validity.

2. Measurability and Reproducibility.

- One of the key aspects in formulating the database structure will have to be separation of the ‘measured’ [and therefore objective] parameters from the computed, estimated, and generated ones.
- The simplest test of measurability is that if more than one measurement of the same parameter is carried out by two or more independent operators, in identical

measurement conditions, the results must match. The reproducibility of any measurement is the best test of its validity.
- The process and technical parameters to be used in measuring any component of the data (irrespective of the parameter used) must be such that they are not subject to external dependencies; and should be a value that is measurable by any independent agency or person.

3. Quality norms and standards.

- The collection of data will have to adhere to pre-defined quality norms and standards. Such standards and quality norms are available, but will have to be made operationally effective for the Indian conditions to be put to meaningful use.
- Any data that do not meet the desired standards may be included as 'untested/sub-standard' data in the structure. Their validity will automatically be always questioned.
- Operationally, it is realized that implementing quality norms requires some additional efforts. However, these efforts and consequent costs must be inbuilt into the database system if it has to be effective.
- The interoperability and integrative nature of the database system will be a key ingredient of its success. The quality norms for the data will have to take these aspects into consideration as well.
- The WG may have to spend some efforts in establishing the 'bare minimum', 'desired' and 'suggested' quality norms for the data as an integral part of its recommendations.

4. Integrativity.

- The data available are generated by different agencies and stored in differing formats.
- The proposed system will have to be capable of integrating (not only during the formative stages, but even on-line eventually) all such multi-faceted data inputs.

5. Accessibility.

- The database (DB) will have to be designed and supported in such a way that it is easily accessible by one and all.
- The DB system will have to be user-friendly.
- All standard DB management systems have inbuilt fire-walls and protection in terms of authorisation, access control, etc. These will have to be integral elements of the system that is designed.
- Easy (authorised) access to the DB system – with increasing connectivity and communication ease – should enable its updating and retrieval in a near real-time basis.

6. Interoperability.

- The Users of the database may have diverse kinds of uses of the data. Therefore, the data formats for storage, retrieval and archiving would have to be such that they do not block access to other systems.

- The hand-shaking with other DB systems (e.g.: the NSDI for geospatial data inputs in terms of terrain information, and CoI for census data) will be an essential and integral requirement of this system.
- The interoperability of the system will have direct impact on how data-storage parameters are defined.

7. Timelines.

- The final success of any such DB system will be first tested on its being able to provide the required data to the intending user in a timely manner.
- The updating frequency, separation of archival from live data, version controls and such other parameters will have to be worked out in detail when designing the DB system.

The CWC and NRSC are currently implementing a plan scheme called WARIS, to bring together all meteorological, hydrological and water resources-related data, as well as project-specific data in as great a detail and spatial disaggregation as is possible. The idea is to place all water related data in a 'standardized based framework to facilitate and progressively refine the tasks of assessment and monitoring, planning and development, integrated water resources management and to provide information for advanced modeling purposes to all departments organizations, professionals and other stakeholders' This is a welcome initiative. But given the inadequacies of coverage, quality and detail in the data currently being collected, the fact that the primary data are not digitized in the GIS format, the reluctance of states to send the data to the CWC[14], the utility of the system is quite limited. The program is a 'plan' scheme which under present convention will have to be reviewed afresh for inclusion in the next plan.

A number of Government-funded projects (like NSDI and NRSC) are being planned or are under implementation to establish digitized very wide scope databases covering different aspects of the country. We are of the view that this does not in any way preclude the proposal to bring together all relevant data related to water resources and their utilization on a single unified and easily accessible digitized platform envisaged in the proposal to establish a National Water Resources Information Centre (NWRIC). Improvements in the data system envisaged in this report and suggestions for introducing greater transparency, standardization of concepts and procedures amply justify this proposal. But it should not be treated as a Plan scheme; it should be sanctioned and funded as a continuing non-Plan activity.

---

[14] Currently the CWC is using a variety of systems to store its data and it has augmented its computing capacities to meet the growing needs of data. Some of the key existing systems in use that were shared with the WG include:

- SWDES – a MS Access 2007 based data storage system with a user-friendly GUI; introduced to field officers and the participating states in HP-I.
- HYMOS – an information system for storage, processing and presenting hydrological and environmental data; used by the CWC for secondary validation only.
- WISDOM – used for archiving validated data and disseminating data to the hydrological data users and general public.
- DSS(P) – being implemented by NIH, Roorkee; DSS (RT) – being implemented by Bhakra Beas Management Board.
- HDA (SW) – currently under implementation under the HP-II by the CWC.
- IWIN – being developed by PRL, Ahmedabad.

The structure, functions of the proposed NWRIC, staff requirements and financial allocations are set out in annexure 20. We support the suggestion that it be an independent and professionally managed entity located in the CWC. It needs, however, to be planned carefully and implemented in a phased manner, as the new data system begins to deliver and the staff with professional skills in designing and managing a large and sophisticated system are trained. Besides professionals from agencies generating the data, it is important to involve outside experts knowledgeable about inter-connections between different aspects of water resources in the design and management of the platform. Such interactions are also essential for evolving better and more meaningful concepts and categories, facilitating comparability of current data across sources, agencies and over time, and enhancing their potential for analytical use of the data on different aspects from different sources.

The expansion in scope and detail of the platform, training programs and in-house research needs to be prioritized in terms of importance and feasibility. We suggest the constitution of a National Advisory committee on water database, comprising experts in the design of digitized databases, professionals from the data-generating and using agencies within the Government, and those experts from academic and research institutions to recommend (a) the scope and content of the data to be included; (b) technical aspects of an appropriate design of the website; (c) the scale and composition of the staff in terms of professional qualification and training; (d) the organizational and managerial structure of the organization; and (e) a program for training of professional manpower and arrangements for implementing it based on a prioritized and phased expansion of the scale and scope of its activities.