LET’S MANAGE WATER

AN ILLUSTRATIVE APPROACH TO UNDERSTAND AND MANAGE WATER FOR SUSTAINABLE DEVELOPMENT

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Category – Water Resources: Availability, Management, Quality

Keywords: Water resource management, water security, groundwater management, surface water management, flood and drought management

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ABSTRACT

“There is a water crisis today. But the crisis is not about having too little water to satisfy our needs. It is a crisis of managing water so badly that billions of people - and the environment - suffer badly." World Water Vision Report.

With the current state of affairs, correcting measures still can be taken to avoid the crisis to be worsening. There is an increasing awareness that our freshwater resources are limited and need to be protected both in terms of quantity and quality. This water challenge affects not only the water community but also decisionmakers and every human being. "Water is everybody's business" and that’s what inspired us to bring visibility of water resources to everyone for enabling decision making and user awareness.

Andhra Pradesh Water Resources Information and Management System (APWRIMS) is an implementation of our solution, a single window access point for all water resources related information of Andhra Pradesh state, assisting all stakeholders (policymakers, managers, water-users) to visualize real-time information on supply and demand of water and to take water management decisions. There are user-specific dashboards, advisories and information available. The User Interface is done in GIS & easy MIS formats for the user to comprehend.

APWRIMS is benefiting more than 60% population in the State, dependent on agriculture. The Crop Planning activity recommended shifting from the water-thirsty Agriculture crops to suitable Horticulture crops. This resulted in an increase of about 1.85 L ha of Horticulture crops. Groundwater levels improved by 2 Meter across the State, despite receiving 14% deficit Rainfall and it helped to optimize the inter-basin transfer of water that provided critical and necessary water to entire Krishna Delta region impacting 1.1 million acres. The

web-based tool has reported 100k+ hectare for critical soil moisture stress and Due to interventions, there were about 4,540 farmers benefitted and this initiative has helped the Groundnut farmers to increase their yield by 23%. We've helped to stabilize an ayacut of 7.11 Lakh acres. Based on the decision support system we raised Advisories it would lead the total water saving potential of 54.3 T.M.C. at a 40% reliability of excess runoff.
Link to APWRIMS: http://www.apwrims.ap.gov.in

PROBLEM STATEMENT

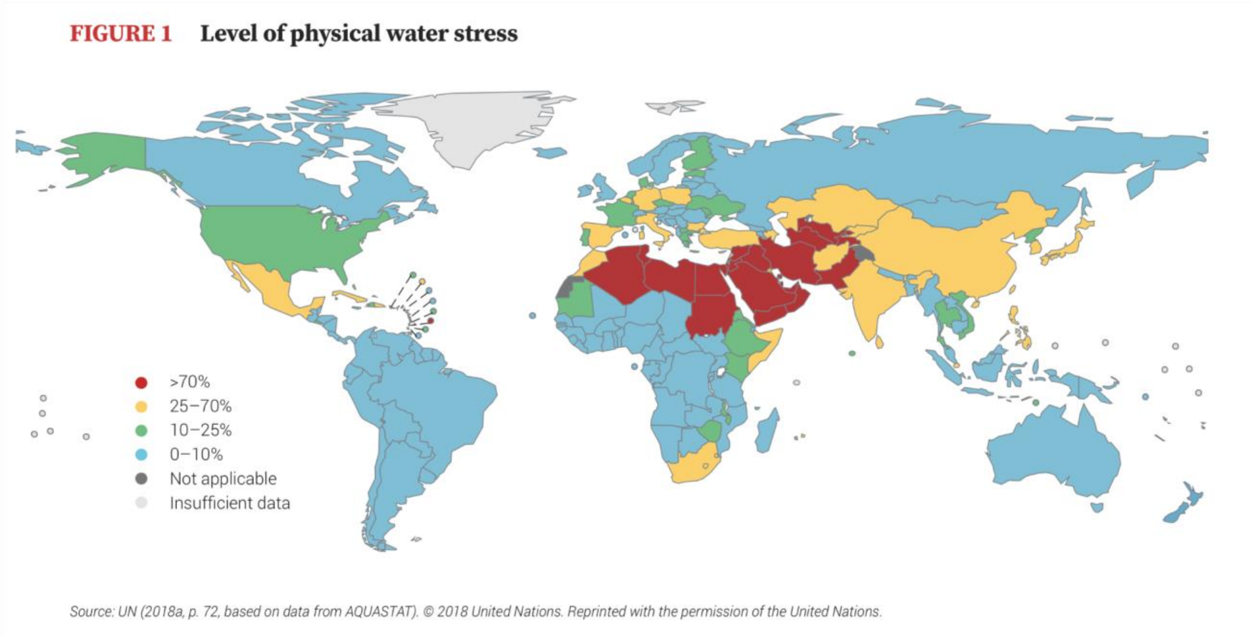


FIGURE 1 : Source- UNESCO

The irony is in India 17.5 Million people are affected by drought and approximately 19 Million were affected by flooding in the last decade (1996-2015).

To understand this problem with context to the global situation we may refer to the latest 2019 Study of UNESCO for water stress.

The reports say that more than 2 billion people are experiencing water stress. 31 countries are facing water stress between 25-70% and 22 are above 70% and are under serious water stress as illustrated in figure 1.

The increasing water demand of Andhra Pradesh, coupled with a geographical condition that half of the state faces cyclone and other half droughts, called for a specific solution to understand the water resources inside the state and provide a mechanism to enable decision making.

The challenge is that integrated water resources management system (WRIMS) should cope with complex issues of water in order to maximize the resultant economic and social welfare in an equitable manner, without compromising the sustainability of vital ecosystems. The information ownership was a major challenge to overcome as it's involved more than 15 different govt departments to consolidate existing data related to water resources.

The key answers to be derived from WRIMS are:

- How much Water do we have now?
- How it is spread across reservoirs, ground water, soil moisture, MI Tanks etc?
- How much and where is water is used across the year?
- Where is Groundwater and Freshwater depleting?
- Which villages are running under water deficit?
- Which locations are affected by drought?
- What can be done to conserve water?

• What are the right locations to put conservation structures?

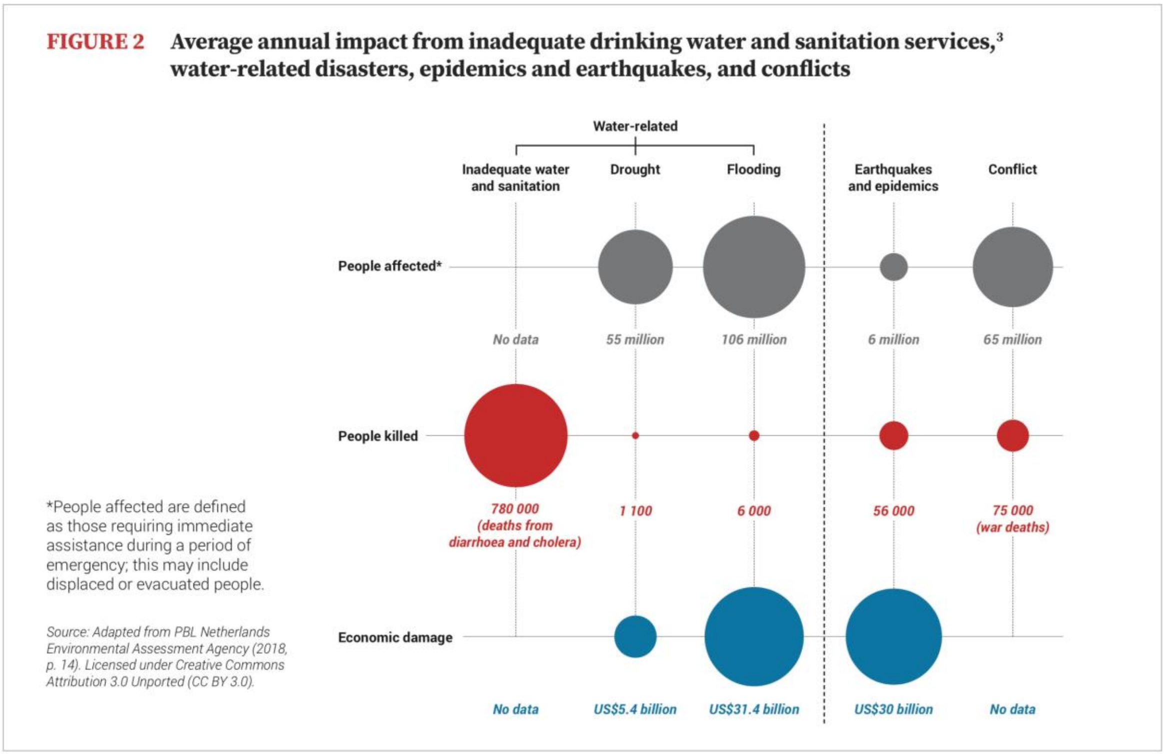


FIGURE 2

Among natural disasters, water is accountable for 90% of deaths. If we consider the number of people died because of water availability, water pollution and sanitation, it will outnumber the previous with killing 157000 people (Figure 2).

PRINCIPLES FOR WRIMS

With the above-stated problems, we came up with principles for water resource information system. The four mentioned points are fundamental pillars on which WRIMS stands.

- Freshwater is limited and essential for sustainable growth
- Water resource management should be based on participation from users, planners and policymakers from all levels
- Water has an economic value and it's a basic human right to have access to clean water
- The human and economic impacts of flood and drought periods can be particularly high, and information systems on these aspects can help to mitigate the risk and to reduce these impacts

Taking the above points we established the beneficiaries for WRIMS, which is given below in table1.

SECTOR	BENEFITS OF WRIMS
ENVIRONMENT	• Understanding Hydrology cycles and their impact on micro factors • Understanding needs for water allocation • Increased awareness for users towards the ecosystem • Individual level approach towards water management • Protecting catchments and advising right way for conservation • Saving common assets as forests, wetlands and other community related resources • Managing water flow and percolation strategies • Improve hydrological balance

	• Understand the impact of climate change to assess the vulnerability
AGRICULTURE	• Agriculture irrigation management with holistic view of water requirement • Ground water recharge strategies • Soil and water conservation strategies • Village level water budget • Data driven decision making considering both cost and benefits • Increasing water efficiency • Monitoring water quality • Understanding detailed impact of existing solutions to improve technology
WATER SUPPLY & SANITATION	• Providing water security and eliminating conflicts between water users • Establishing economic value of water • Water demand management • Optimizing cost of providing water • Computing resources and communication networks • Project monitoring and control

TABLE 1

Managing water resources in transboundary basins requires sharing data and information for various activities: planning, monitoring, and assessment, prevention and alerts, etc. Unfortunately, its often difficult, both for structural and for technical reasons (difficulties related to information collection, harmonization of data formats, definitions, analysis methods, frequency of data collection, density of monitoring networks and data processing), as well as standard difficulties (data that is dispersed, heterogeneous, incomplete and rarely comparable), more generally, state authorities may be reluctant to provide neighboring states with information that they consider strategic. Also, the economic value of water used for hydropower, agricultural irrigation and navigation may increase this reluctance.

We have stated in the problem statement that becomes extremely difficult due to multiple levels of authorities involved. To simplify the same below the sample framework of authorities will help you out understanding the same (Figure 3).

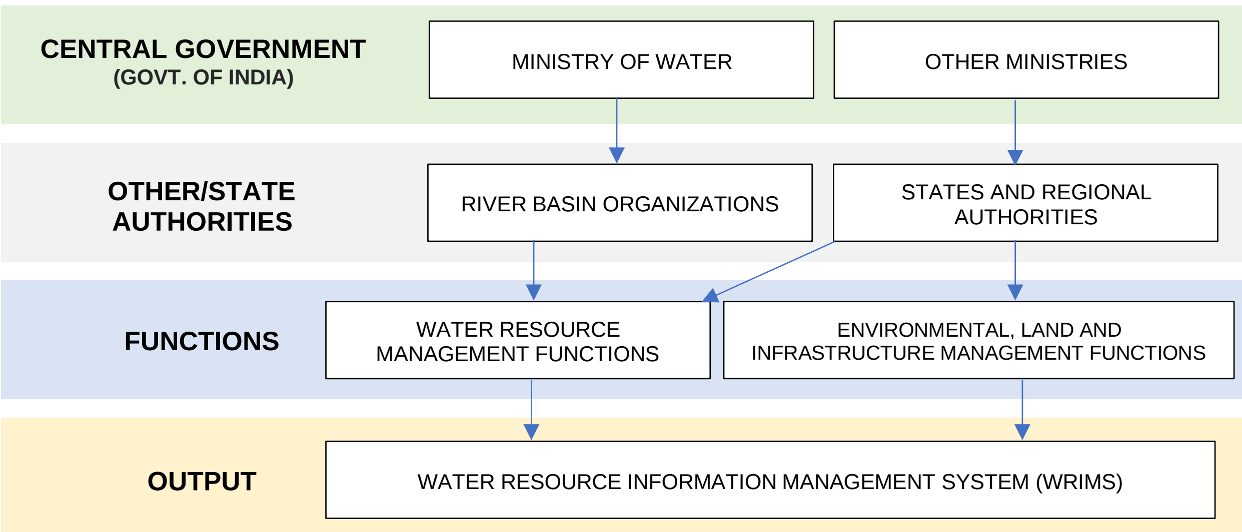


FIGURE 3

Information systems are thus key instruments for the development of integrated management of transboundary basins: they are tools designed to facilitate the production and sharing of information expected by stakeholders.

Given the situation, their development requires working firstly on institutional, organizational and governance issues, and secondly on technical issues related to the construction of the information system. At the organizational level, it is necessary to have prior confirmation of the political will to work together to produce shared information, and then to agree on the governance framework and organize the system's development in close cooperation with stakeholders to continuously look for "win/win" solutions.

With the consideration of the above flow, the WRIMS should synchronize all units under one umbrella to collect data from every source and return meaningful insights for all stakeholders as illustrated in figure 4.

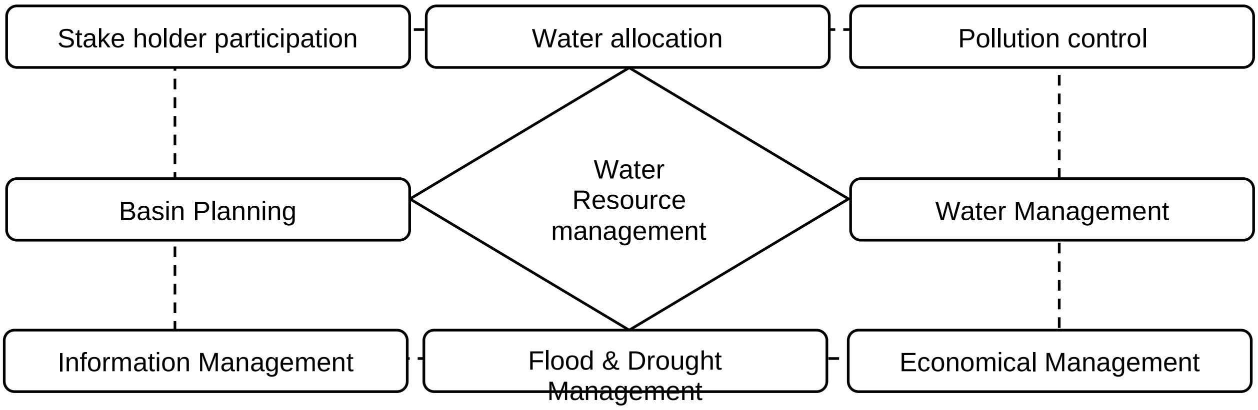


FIGURE 4

To achieve the above, it required major work towards getting, understanding the data and applying Artificial intelligence and Machine Learning algorithms to automate the process and eliminate constant human interventions. We will learn about the same in the upcoming sections.

DATA & TECHNOLOGY

Effective WRIMS needs an objective basis for planning where Stakeholders & the public have to be informed to gain political support and commitments for WRIMS, then appropriate information has to be organized, retrieved, acquired and maintained or updated. To achieve the desired results, we may start with a very basic workflow of information management as illustrated below which became complex in the account of its components over time.

FIGURE 5

While developing APWRIMS, during data capture process we collected information's from, approximately 1 million geo-tagged Water bodies and 1.3 million geotagged bore wells, along with various layers like administrative, hydrological, soil, agriculture, satellite, aquifer, LULC, Rivers & Canal, Drainage network, DEM, Command Areas, etc. (are included). Approximately 3 Lac point data comes every day from different sources like Automatic Weather Stations, Reservoir Level sensors, Ground Water Level sensors, River and Canal level sensors, etc.

Information for different data points come from Satellites/ models/ IMD/ ISRO/ WRD, among other sources. All these data come in different format and frequencies and hence impose a big challenge to sanitize validate and feed into a system for their actual impact. For a sample below table (figure 6) explains data which are required.

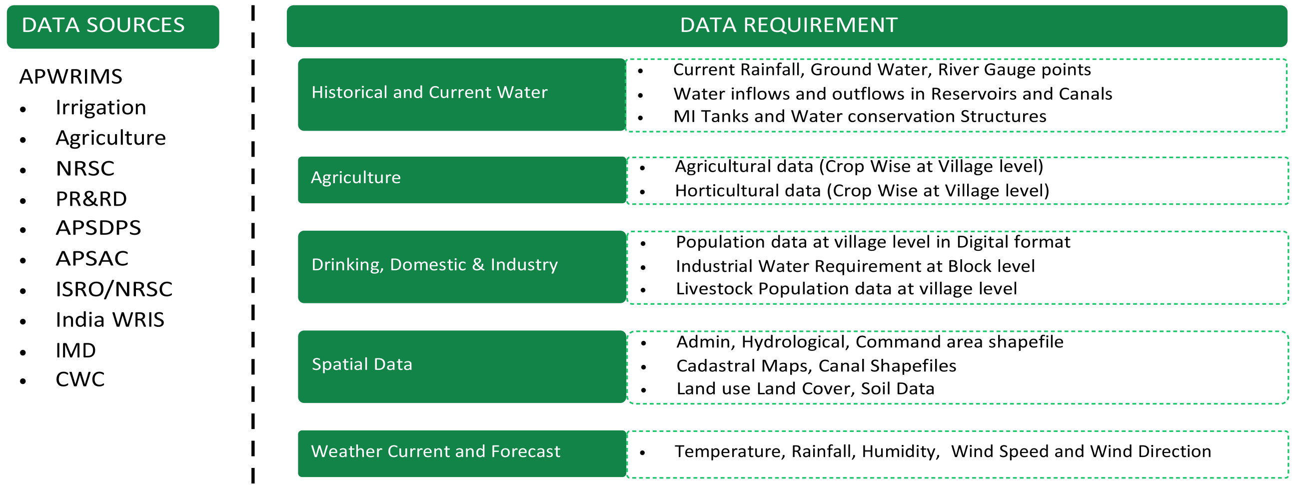


FIGURE 6

The system is designed to automatically ingest any form of data from various sources like satellite, sensors, mobile App, any model, or 3rd party data sources. The system is designed specifically to deploy an event based topology that makes sure any data received any time is not lost and processed and stored by the system for further use. The system further performs validation of the incoming data and transforms it into various water demand, water supply, and environment-related component.

The system is made flexible to host various computational and analytical components
i) Ready off the Shelve Hydrology or other Scientific models
ii) Construct new Scientific simulation models
iii) Build optimization models
iv) Deploy Machine learning and Artificial Intelligence algorithms

The processed information is consumed by various decision support modules to provide dashboards and actionable insights. Finally, results, information, and data are presented to different users through MIS / GIS dashboard, Mobile APP, or SMS, etc.

All the components in the system are built using open source and license-free software components helped in reducing the development cost system and also the system is flexible, and it avoids lock-in and lockout risks. Big data technologies are used to ensure the system can scale horizontally and handle large volumes of data. The database will be set up as a 3-node active cluster so that there is no single point of failure and the data can be available in high availability architecture.

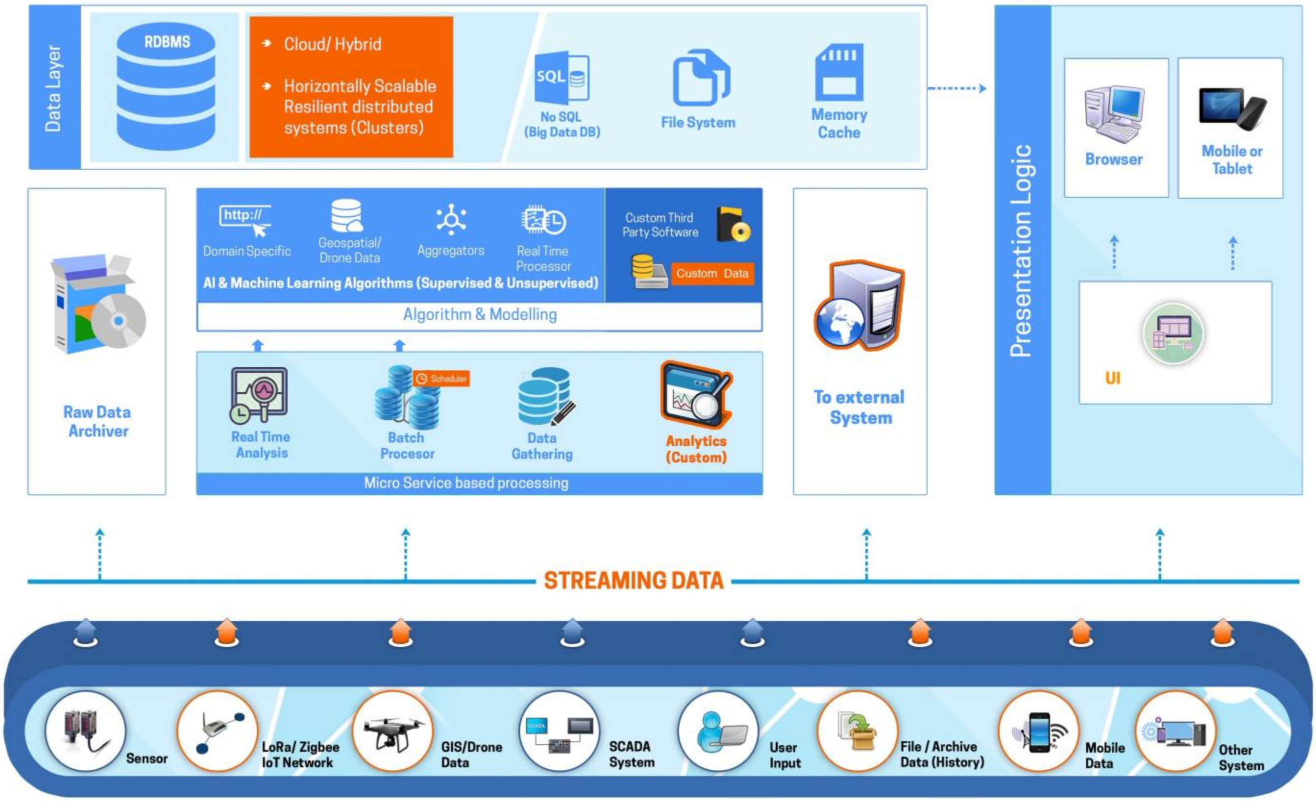


FIGURE 7

All time-series data will be stored in a big data database, whereas the configuration data will be stored in a relational database. Both the big data database as well as the relational database will be open source databases. APWRIMS is built on a modern scalable platform that uses license-free open sources tools and components written in JAVA, R, Python, Angular JS, Node JS, HTML, CSS, etc. The platform is built with future expandability designed into the architecture that will allow easy vertical and horizontal scaling. The system is deployed with a low cost of operation and maintenance structure. The technology stack for above has been illustrated in figure 8 given below.

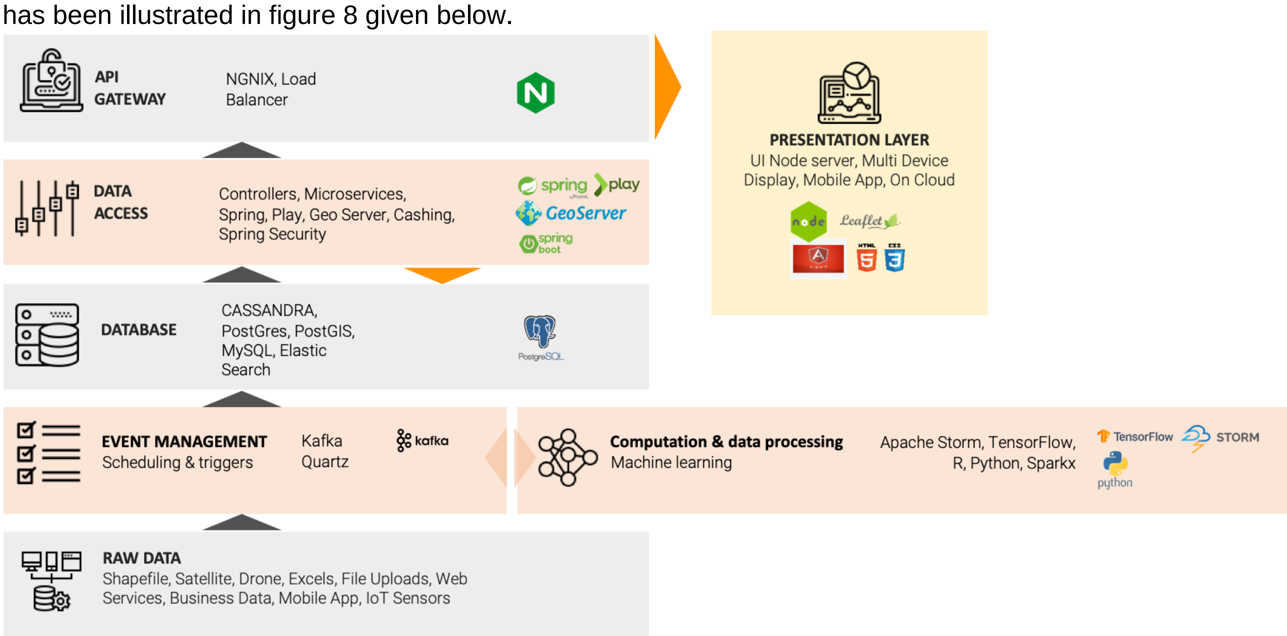


FIGURE 8

UNDERSTANDING WATER RESOURCES

The data does three things; Water Resources Information, Water Resources Management, and GeoPortal. The objective of the above stage is to produce results and dashboards which are made for decision making and empowering its stakeholders. The below representation (Figure 9) can be used to understand this better.

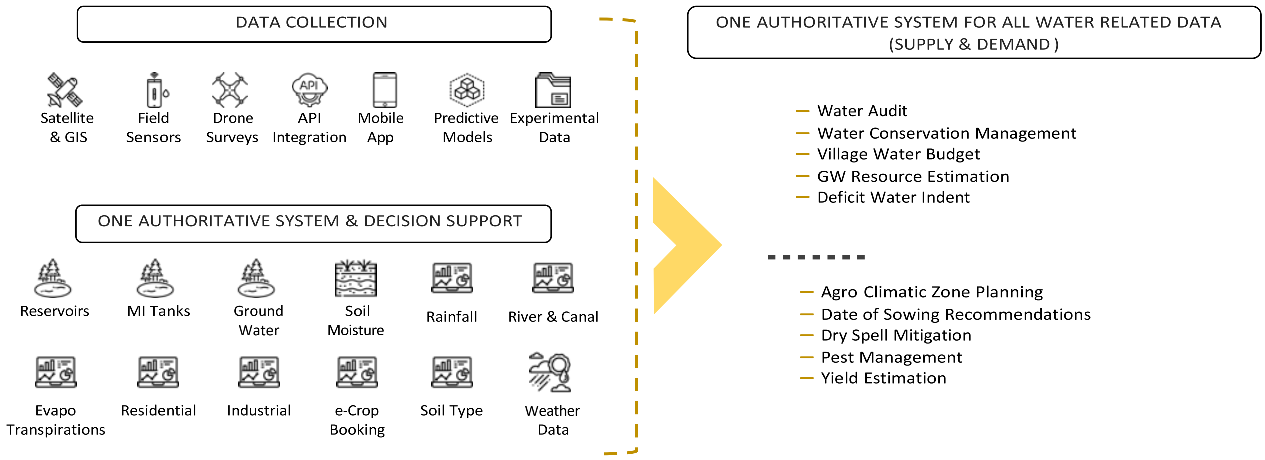


FIGURE 9

There are much more to be done after knowing the current status of water resources. There are complex hydrological relationships which need to be decoded. Hydrologic processes considered in the model are shown in Figure 10. They include reservoir operations, flow distribution, conveyance and recycling, irrigation water use, and interactions between surface and groundwater. This can be extended further to describe the water balance at the crop field level and the balance at M&I demand sites, respectively.

The major hydrologic relations include

- Flow distribution and balance from river outlets/reservoirs to crop fields or municipal sites;
- Recharge to and discharge from surface and groundwater;
- Crop evapotranspiration from fields;
- Effective rainfall (rainfall stored in the crop root zone, which can be used for crop growth);
- Water balance in the crop root zone, including surface runoff, percolation, drainage, and groundwater abstraction;
- water balance in M&I demand sites, water distribution, seepage/leakage, drainage, and treatment;
- Return flow from irrigated and M&I areas; and Hydropower generation.

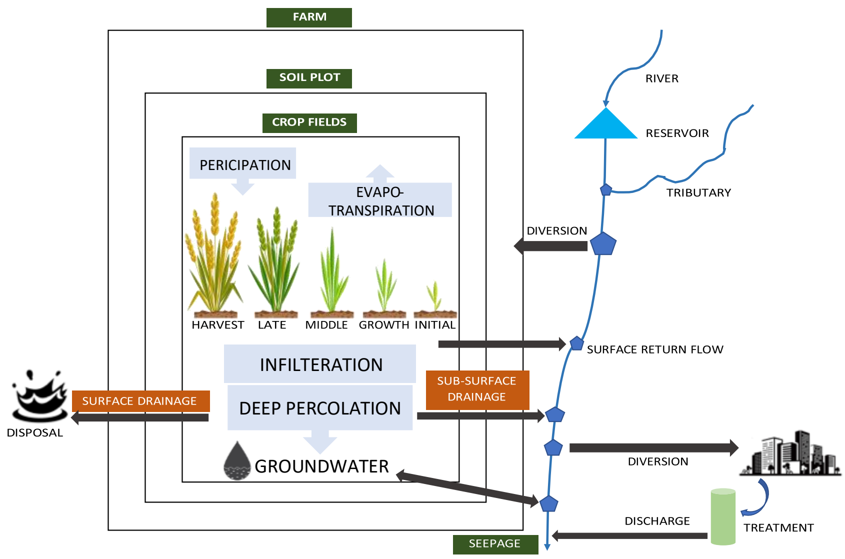


FIGURE 10

There are many models being used in APWRIMS, few are mentioned in table 2.

Hydrology Model	Use of Model
Variable Infiltration Capacity Model (VIC)	Rainfall to runoff value calculations
VIC Routing Model (RVIC)	To create drain network & flow accumulation
Network Flow Model	To calculate runoff values from last 30 yrs rainfall data
Crop-Specific Water Balance Model	To calculate crop specific water demands
GEC Model	To estimate ground water
Penman Monteith	determining reference evapotranspiration
Various Optimization Algorithms	Agro eco crop planning models

TABEL 2

One of the most important models is watershed conservation model as it works at the very fundamental unit. Watershed model is usually performed over a micro area by understanding the complete hydrology and ecology around the selected geography. Let's understand this model in detail, concerning the implementation of same inside APWRIMS.

Watershed Conservation Modeling (WSC Model)

It is semi-distributed network model which is used to predict the amount of direct runoff that is being conserved across various water conservation structures such as MI Tanks, farm ponds, check dams, percolation tanks, etc., in any given region.

- It uses the geo-tagging and other information about various water structures to map the structures to their corresponding catchments areas.
- As of now, more than 40,000 MITanks and more than one million other water conservation structures are geo-tagged in the state of Andhra Pradesh.
- It then uses streamflow simulation, coupled with a ‘leaky bucket’ model for water balancing, to predict the amount of runoff that has been conserved and the amount that is overflowing to the downstream region.
- For any given location, say a village, all of its natural drainage network outlets are identified and then the corresponding flows going out through the drainage exit points are aggregated to get the total amount of water being lost from the village. [The flows at the outlets/exit points are obtained from the streamflow simulation model mentioned earlier]

Catchment Area Mapping Tool - Used in the GIS

Catchment Boundary of a given point is defined as the extent within which water will flow through that point if left unhindered, it is computed. The Catchment is defined for a given point on a stream. It is defined as the area encompassing the network of all the streams contributing water to it. It is also called full catchment. The individual catchment of a point is defined as the area compassing all the streams which only contribute to that particular point and no other point for a given set of point.

Inputs required: SRTM30 DEM File (which contains the elevation value at each pixel) and Flow direction file generated from the dem file.

Variable Infiltration Capacity Model (VIC)

VIC model is a large scale, the semi-distributed hydrological model which takes time series of daily or subdaily meteorological data as input (rainfall, temperature, wind speed, radiation, etc.,).

- It also takes non-meteorological data such as Land Cover information as input.
- VIC simulates Land-atmosphere fluxes and the water and energy balances at the land surface, at a daily or sub-daily time step.
- The output of the VIC model includes Runoff, Soil Moisture, Potential Evapotranspiration, Base Flow, etc.. at a smaller uniform grid level.

VIC Routing Model (RVIC)

The RVIC model is a streamflow routing model used as a post-processor with the VIC hydrology model.

- It takes Runoff from the VIC model as input and gives flows at the given outlet points concerning time.

- The routing model is a source-to-sink model that solves a linearized version of the Saint-Venant equations.]
- It utilizes Impulse Response Functions (IRFs) to represent a distribution of flow at the given outlet point concerning time from an impulse input at each source point. IRFs are linear and timeinvariant.

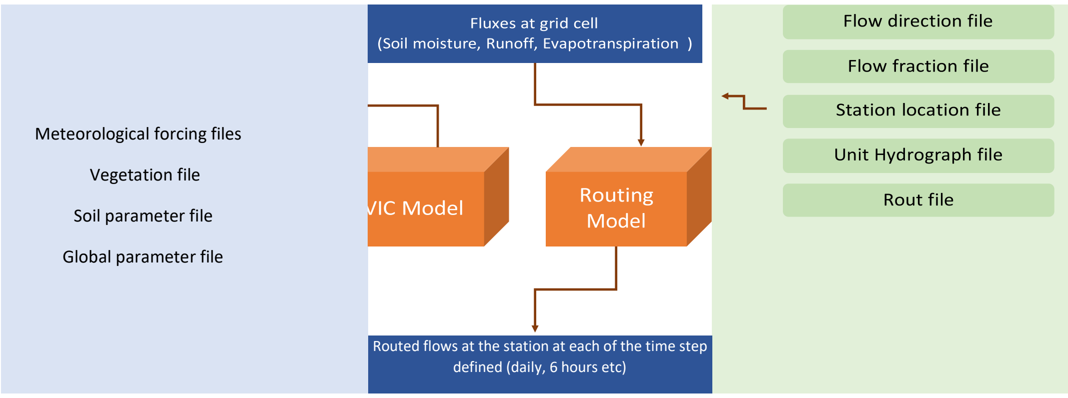


FIGURE 11

Network Flow Model

Rainfall to run-off model is important in estimating the amount of the runoff generated from rainfall daily which will be used by the network water conservation model to estimate the amount of the runoff that is conserved and runoff that is available for taking up additional water conservation activities.

- The network flow model is a one-dimensional flow simulation model, which forecasts the inflows in real-time and raises the appropriate flood alerts at any given location on the river reach.
- It uses intermediate catchments runoff inflows obtained from RVIC model and integrates with the observed real-time sensors data from the reservoirs and gauge stations.
- It essentially utilizes the simple fact that “the water released at any given upstream location, at the current instant of time, will reach any corresponding downstream location in the future”.
- The time the upstream release takes to reach the downstream location would depend on various factors such as distance, the velocity of water, slope, etc.,
- These upstream flows are synchronized with the forecast runoff inflows from intermediate catchment area obtained from the RVIC model, to predict the net inflows.

The use of same is illustrated below in Figure 12. You may see how the runoffs are getting calculated and after conservation how the remaining is distributed. It’s important to ensure the proposed structure is not negatively impacting the ecosystem.

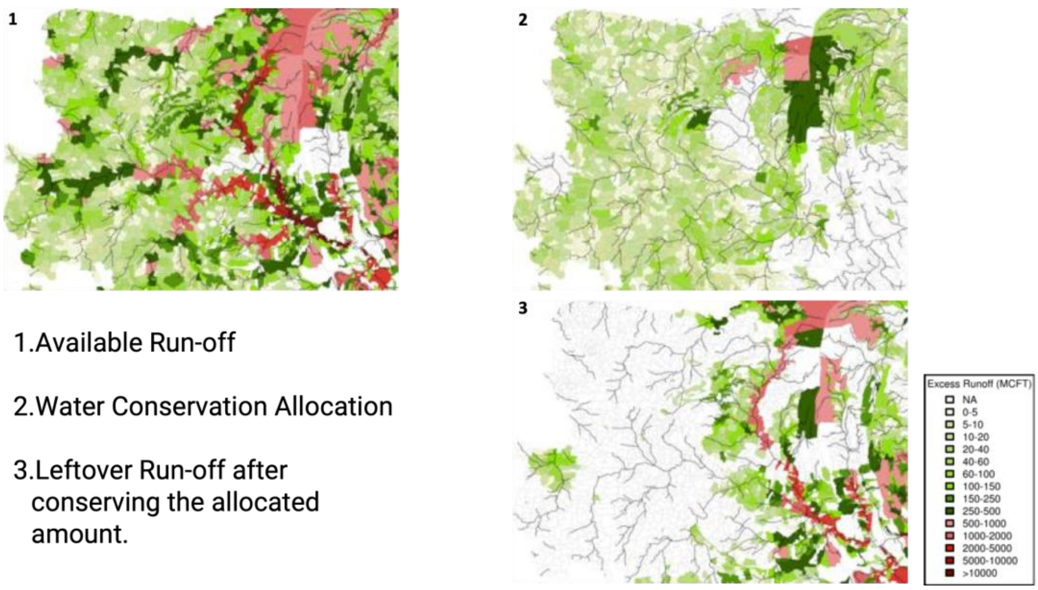


FIGURE 12

DECISION SUPPORT SYSTEM (WEB PORTAL)

An interactive decision-support system (DSS) can help experts prepare water resource management plans for decision-makers and stakeholders. The structure of our DSS can be understood from the block diagram given below in figure 13. The boundaries of the economic system of a specific resource problem are typically different from those of the hydrologic system. Whereas the economic component typically relates to political and administrative boundaries, the hydrologic scale usually relates to the river system or watershed.

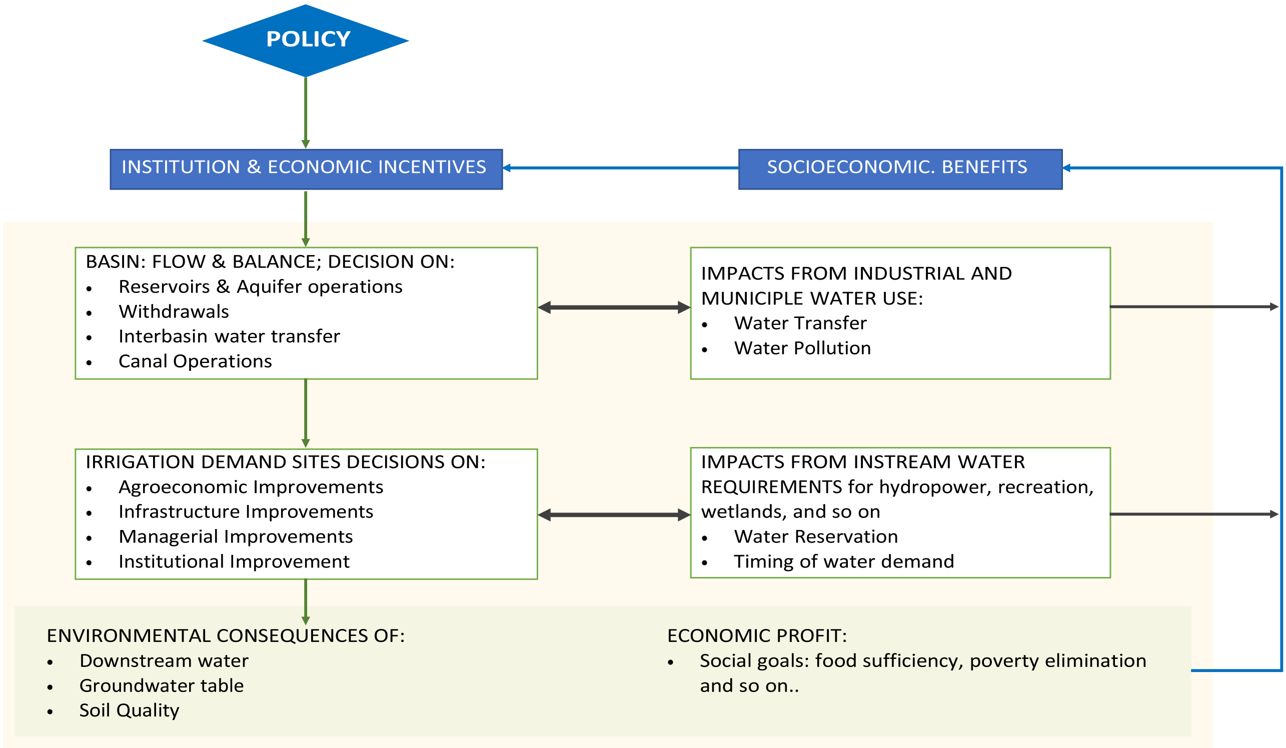


FIGURE 13

By taking the complex structure as illustrated above, its technology which makes it possible to unify all the view and support the decision-making process. The design incorporates visualization techniques such as circle views, grid layout, small multiple maps, and node simplification to improve the data readability of water distribution systems from macro to micro-level, with intuitive GEOPORTAL. The geoportal serves the purpose of one Authoritative System for all water-related data Supply, Demand, Operational, Environmental factors, etc with near real-time visibility into 90% of all available water such as Ground Water, Surface Water components such as Reservoirs, Canals, Minor Irrigation Tanks, etc. The artificial intelligence and machine learning play a pivotal role to integrate all the information and produce the ultimate results which empower decision making as illustrated in figure 14.

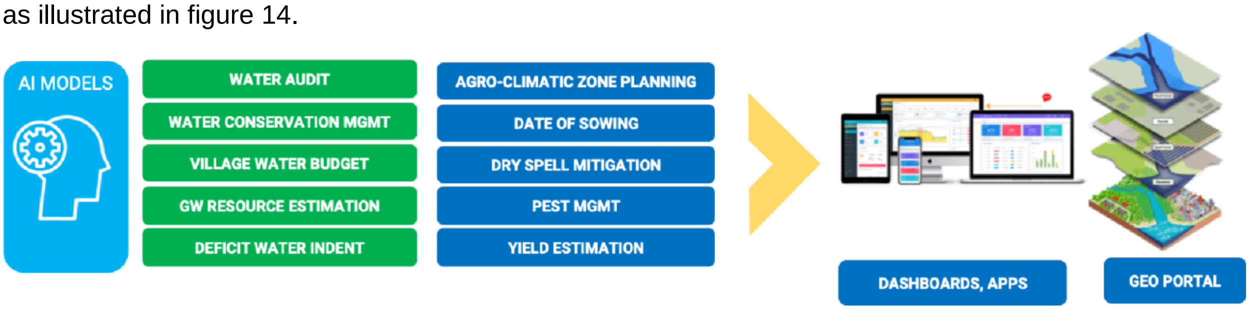


FIGURE 14

For example, the key components for the geoportal which we developed in APWRIMS are:

- Water Balance and Water Audit
  - Water Audit provides a data-driven hydrological framework that facilitates traceability and accounting of the water resources across the state. It is a realistic assessment of supply, storage, usages, losses and outflows in the present or an earlier “water year”. This module results in holistic water auditing and accounting that can help authorities for better management of water resources and planning long-term projects-based intervention.
- Drinking Water Stress ○ Predict onset of Drinking Water Stress at Habitation in Advance of 1 week by using ground water level tracking combined with use of historical ground water and start drinking water tank supply data to determine minimum draw level.
- Village Water Budget ○ An interactive Decision Support system at a village level, that is based on current Supply and Demand is required for the village. This module results in giving visibility over surplus and deficit areas at a village level.
- Ground Water Resource Estimation ○ Estimating Ground Water Resources is done manually at present and there is a need to automate Ground Water Assessment, Categorization, and Evaluation. This helps in understanding and visualizing the areas that are at various stages of exploitation of groundwater. This module results in identifying the villages and areas where Dynamic GW is Over Exploited, Under Exploited and Safe. Also, better Water Conservation Management based on GW Recharge, draft, and potential.
- Minor Irrigation Tanks Vegetation Estimation ○ There is a need to find the infiltration and the extent of infiltration in & around Minor Irrigation Tanks. Key stakeholders get information regarding the extent of vegetation in a Minor Irrigation Tank thus impacting the water storage capacity. This module results in decision support for corrective actions to be planned and taken to ensure that the Minor Irrigation Tanks are used to their maximum potential.
- Reservoir Management ○ To have all the reservoir related information such as estimation of inflows and outflows based on Rainfall-Runoff, Demand, Gross Capacity, Current Storage and Flood Cushion, etc. at a Reservoir type and River Basin view in a predictive Decision Support System. Based on predicted and current inflows, demand, flood cushion and other parameters, optimized reservoir releases. This module results in a Unified dashboard that gives a holistic view of the reservoir enabling optimized management of Reservoirs.
- Soil Moisture based Irrigation and Canal Management ○ At present, there is no visibility of Water Flow at important points in the irrigation canal network and there is a need for decision support to advise releases based on Soil Moisture and Crop Water requirement. This module results in transparency in water flow at different critical points in the canal network and advisories based on Soil Moisture and required water.
- Watershed Management ○ There is a need for better management of watersheds where there is a decision support system that looks at Rainfall-runoff, slope, LULC, and other parameters and provides decision support on best possible sites for a Water Conservation structure and effectiveness of existing structures. This module results in the identification of new water conservation structures, a system to evaluate the effectiveness of existing water conservation structures.
- Agro-Eco Crop Planning ○ There is a need to optimize the Cropping pattern to maximize Economic Yields by maintaining water balance, Soil, and other scarce resources. The recommendations of the cropping patterns would be given after considering the Soil Type, Rainfall, Sources of Water & other external factors such as markets access, market linkage, after farm value chain, access to seeds, access to finance, access to fieldworkers, etc. This module results in Cropping pattern advisories based on various constraints like water, soil, etc. to optimize the economic yield.
- Crop Date of Sowing Advisory ○ The date of sowing is an important aspect of crop yields as the crop water requirement at the critical stages determines the crop success or failure. The farmers have limited visibility over the weather conditions in the future. The Date of Sowing advisories module ensures that the crops are sown with congenial weather and water conditions, along with historical probabilities of success thereby increasing the chance of crop success.
- Crop Soil Moisture Stress Advisories ○ The soil moisture stress affects Crop yields to a large extent. The timely interventions to mitigate Soil moisture stress provide both Protective and Productive irrigation. This module results in timely advisories for mitigating crop stress & advisories to intervene the same.

DECISIONS & IMPACT

To understand the decisions and its impact first we need to understand the different functions, their objectives, and their indicators. As part of a program of capacity building support indicators have been developed that are based on the implementation of the integrated approach to the sustainable management of water resources. The indicators are presented as a minimum set and therefore do not completely measure the objectives described for good water resources management.

Function	Water Management Objective	Progress Indicator	Unit/Definition
Water Allocation	Management of major water users like authorities	1. View of all Groundwater resources	Review. Extraction limits and exploitation status
	Water allocation for sustainable use, economic efficiency and on equality principles	2. Allocation Criteria based on demand	Review. Examine allocation criteria for example soil moisture stress
		3. Social reserves	Review. Monitoring reservoirs and understanding flow and need of conservation and allocations to subunits
Pollution Control	Extent of water pollution	4. % of surface water quality	%. Number of samples below set standard.
		5. % of ground water quality	%. Number of samples below set standard.
	Major polluters and pollutants	6. Type of pollution	List of pollutants and their cause
Monitoring	Effectiveness of allocation system	7. Proportion of water allocation	%. From monitoring visits, the number not complying with conditions divided by the total number of visits.
	Pollution Control	8. Pollution levels	%. From monitoring visits, the number not complying with conditions divided by the total number of visits.
	Knowledge of water resource availability	9. Number of water resource monitoring status	Number. Number of stations with reliable data records.
		10. Total water storage capacity	Mm3. The water storage capacity in artificial storage structures

		11. Ground water stations reporting negative balance	%. Comparison of water levels over a 5-year period.
Basin Planning	Basin planning synthesis technical and social priorities for the basin and acts as a basis for action and accountability to the stakeholders.	12. Water management activities driven by Basin plan.	Review. Examine the link between the basin plan and current water management activities.
		13. Stakeholder priorities reflected in the basin plan.	Review. Examine the basin plan for stakeholder consultation and content.
Information Management	Essential data is processed and packaged as information at the right level for specific managers and stakeholders to support transparent decision making and to gain commitment and political support for the decisions made.	14. Data base is established in formats compatible with other river basin organizations.	Review. Data base is transferable across basins in the country and for transboundary systems.
		15. Water management information is available to managers and other stakeholders as required.	Review. Examine availability of basin information and reports on water resource management indicators.
Stakeholder Participation	Effective cooperation between government agencies with responsibilities for water management or water use in the basin.	16. Synchronizing different units inside government	Review. Data inflow and frequency of information gathered from various departments
	Stakeholder participation is institutionalized in the management of the river basin.	17. Clear roles and responsibilities in water resources management	Review. Examine basin water management structure for stakeholder organizations and allocated management roles.
		18. Representation in decision making bodies at all levels.	Review. Participations from NGO, Water societies, Public reps and Authorities

TABLE 3

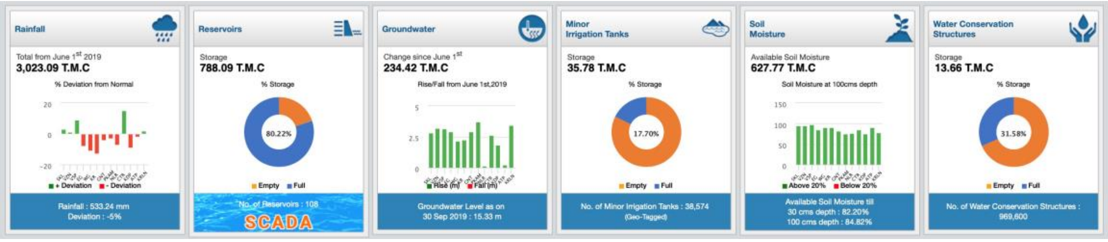
IMPACTS:

- APWRIMS is benefiting more than 60% population in the State, who are agricultural dependent.
- The Crop Planning activity recommended to shift from the water-thirsty Agriculture crops to suitable Horticulture crops. This resulted in increase of about 1.85 L ha of Horticulture crops.
- Groundwater levels improved by 2 Meter across the State, despite receiving 14% deficit Rainfall.

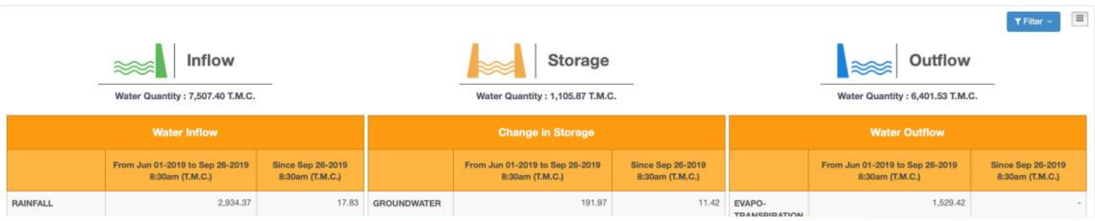
- Helped to optimize inter-basin transfer of water that provided critical and necessary water to entire Krishna Delta region impacting 1.1 million acres.
- 100k+ hectare reported for critical soil moisture stress and Due to interventions, there were about 4,540 farmers benefitted and groundnut farmers increased their yield by 23%.
- Saved 970 MW hour of energy for pumping the groundwater for irrigation purpose which costs about INR 4,850 million.
- Stabilizing an ayacut of 7.11 Lakh acres
- Lift scheme management: After the revival of the LI Schemes, the ayacut irrigated is increased substantially from 3.81 Lakh acres to 6.15 lakh acres
- Based on the decision support system we raised Advisories it would lead the total water saving potential of 54.3 T.M.C. at a 40% reliability of excess runoff.

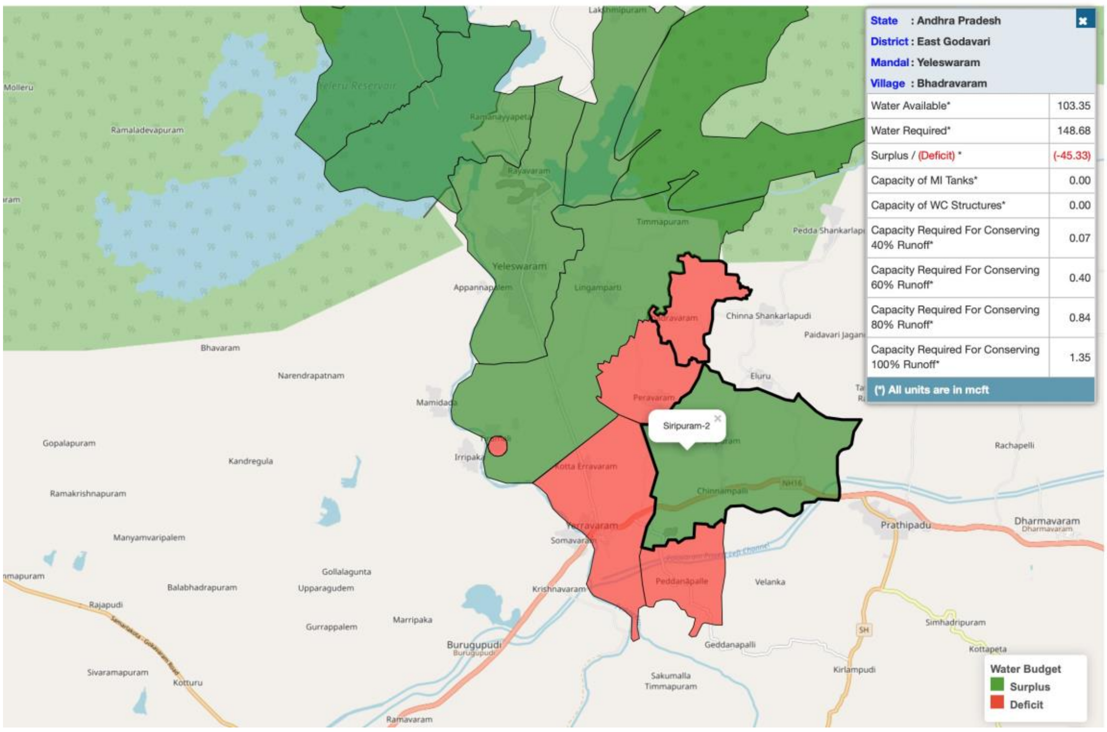
APPLICATION SNAPSHOTS

APWRIMS DASHBOARD



WATER AUDIT





VILLAGE LEVEL WATER BUDGET

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