

## CHAPTER 8

# Downscaling IWRM plans from basin to districts: IWRM plan for Pali district in Western Rajasthan

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### 8.1 Introduction

The European Union Special Partnership Programme (EU-SPP) sought to assist the Government of Rajasthan from 2007 to 2014 to implement the State Water Policy that was based on Integrated Water Resource Management (IWRM). One of the several activities undertaken by the Technical Assistance (TA) team of the EU-SPP was to downscale basin-level IWRM plans to the district level, i.e., from a hydrologically defined area to an administratively defined boundary. The study had three objectives: (1) to prepare rapid water accounts for Luni river basin and to study the water infrastructure and water access and use in the basin; (2) analyze the droughts in Luni basin and suggest mitigation strategies; and, (3) discuss the methodology for preparation of district IWRM plans and apply the same for Pali district. While the findings of first part of the study have been detailed in [Chapter 7](#) of this volume, this chapter presents the findings on the last part of the study.

The chapter accordingly describes the analytical procedures for district IWRM planning, presents the estimates of water balance for Pali district under the current and future water management scenarios (done for the purpose of illustrating IWRM planning process), and discusses key interventions to close the demand-supply gap in 2025.

### 8.2 District IWRM planning

Water resources development and management planning under the IWRM approach is basically about meeting the future demands of a region's

socioeconomic and environmental systems using the available supplies from the natural water system (here the river basin), without threatening its integrity.

In the context of an administrative boundary like a district, which falls entirely within a river basin, planning for water resources development and management activities using the IWRM concept requires taking cognizance of the opportunities and constraints for augmenting water supplies and reducing water use, giving due consideration to other parts of the basin (in which the district falls) due to their socioeconomic conditions and hydrological dependence. This interdependence affects water demand and water availability calculations, as well as the impacts of a highly variable rainfall and climate, as detailed here.

### **8.2.1 Water demands**

The impacts of intensive water harvesting in an upper catchment district (like Pali, in the Luni river basin) will have negative impact on stream flows in the stretches of Luni river passing through the downstream district of Barmer. Hence, if the entire basin is considered in planning, it would help understand the limits to water harvesting structures in the upper catchment districts.

Conversely, what is being planned in the lower parts of the basin should take cognizance of the situation in the “district” in question in terms of water availability, their future water demands and new development plans, including water use efficiency improvement plans.

### **8.2.2 Water supplies**

While water demand estimation can be done independently for a district, the water to meet the district demand can be located outside the district’s administrative boundaries. Further, since there could be losses while water is being transferred from supply sources to the demand sites, the water supply requirement will be higher than the actual demand at site. An example is the seepage losses in canal systems, due to which more water must be supplied from the reservoir than what is required to meet crop water demand. However, this excess water is not permanently lost from the system and would be available for reuse from the shallow groundwater underlying the area through which the canal network passes. Further, not all the water supplied

to the demand sites will eventually get consumed, and some of the water could return to the system as “return flows.” Such return flows could be significant in surface irrigation commands and could contribute to the groundwater system or drainage channels—which in turn could contribute to the available water resources in the lower parts of the basin as “new water.” Such return flows are also significant for domestic demand, particularly in urban areas, and nearly 80%–85% of the water consumed domestically would be available as wastewater flowing into the natural sinks.

On the other hand, demand reduction measures (particularly in agriculture) implemented in an area (district), through the use of efficient irrigation technologies, can have negative implications for water resource availability in the same area or its downstream parts in the long-term; and, this is particularly true if downstream users are heavily dependent on groundwater in the shallow aquifers due to significant reductions in return flows to groundwater in the lower parts of the basin (Batchelor, 1999; Howell, 2001). When considering water use efficiency or productivity at the catchment or larger scale, interactions between different units in the landscape as well as different water users must be considered (Batchelor, 1999; Seckler, 1996).

For this reason, how water gets augmented or used up or saved in one parts of the basin (for example, in a district) can also influence the availability of water resources in other parts of the basin. This means that water demand and supply estimation—which is the basis for water resource planning—should be done at a spatial scale that captures the dynamics of interaction between physical systems affecting water availability, such as surface water-groundwater interactions, land use changes, and stream-flow interactions.

### 8.2.3 Rainfall and climate variability

Water supplies in a basin to meet water demands are also a function of the climate, which experience very high variability. With the variation in rainfall from year to year, stream flows, groundwater recharge, and soil moisture availability are likely to experience significant variations. This can also induce significant changes in the demand for irrigation water between a dry year and a wet year, as during drought years the demand per unit area of crop could increase and reduce drastically in a wet year. Therefore, it is important to do a temporal analysis for water assessment and planning, involving several years of data with dry, wet, and normal years.

## 8.2.4 Challenges of district IWRM planning

Five key issues to be explored in district level IWRM planning are the following:

- *Intrabasin water transfers*, i.e., the movement of water from the district under question to other parts of the basin, which are relatively “water scarce”
- *Water imports* from parts of the basin that are “relatively water rich” to the district
- *Multiannual storage of water* in the basin through reservoirs, to store water in excess-rainfall years for supply in low-rainfall years
- *Limits to water resource augmentation* instead of continuing to build such schemes; and
- *Transfer of water savings*, i.e., “saving water” from areas where opportunities for demand reduction are higher, for release to parts of the basin facing severe water deficits.

The next sections analyze the different components of water demand, i.e., for irrigation, domestic and institutional uses, livestock and industry, and then the available sources of water supply, before analyzing demand-supply gaps, and how they can be addressed.

## 8.3 Analyzing water demand

While it is rather easy to estimate the existing supplies from the available sources, the estimation of potential water supplies to meet the future demand is one of the most complex issues involved in district IWRM planning. This is because of the complex dynamics of interaction between upper and lower catchments, and surface and groundwater. Due to these interactions, water development in the upper catchment can influence water availability in lower catchments and change in water use efficiency improvements in one part of the basin can affect surface or groundwater availability downstream, though with time lapse. Therefore, in water balance studies required for district IWRM planning, it is important to carry out water assessments using basin as the unit of analysis, as it integrates the complex interactions discussed above.

### 8.3.1 Irrigation water demand

Irrigation water demand estimation should be done for typical rainfall years, i.e., wet years, dry years, and normal rainfall years, to account for the variations in water demand rates and the areas under irrigated crops

between years. Given irrigation water demand data for each irrigated crop, including the rain-fed crops, which receive supplementary irrigation during drought years, the irrigation water requirement for crop  $k$  at time  $t$  is calculated as follows:

$$\Delta_{\text{IRRIGATION},k,t} = (\text{ET}_k - P_{\text{EFF},k,t}) / \text{IE}_{\text{APPLICATION}} \quad (8.1)$$

where  $\text{IE}_{\text{APPLICATION}}$  is water application efficiency for the irrigated field, expressed as a fraction, for which a reasonable assumption can be made, depending on the irrigation method.

Eq. (8.1) suggests that the irrigation demand for the same crop could be different for different years and for different seasons within the same year. Also, irrigation water requirements for rain-fed crops would become significant in drought years, while it might be nil during wet and normal years, depending on the crop duration.

The total water demand (TWD) for irrigation can now be estimated as:

$$\text{TWD}_{\text{IRRIGATION},t} = \sum_{k=1}^n \binom{n}{k} A_{k,t} [\Delta_{\text{IRRIGATION},k,t}] \quad (8.2)$$

where  $\Delta_{\text{IRRIGATION},k,t}$  is the amount of irrigation water dosage to the crop  $k$  in year  $t$ ;  $n$  is the total number of crops in the region;  $A_{k,t}$  is the area under crop  $k$  after a time of  $t$  years.<sup>a</sup>

Given that a growing population would cause the demand for agricultural output to increase in the district (and the basin as a whole), there would be greater pressure to increase the area under irrigation. One way to incorporate this in the agricultural water demand estimation is to keep the total cropped area (of individual crops) per unit of population for future years at the same level as that of the present. This means that population growth would be the main driver of agricultural water demand growth, and total future irrigation water demand  $A = \Delta_{\text{APPLICATION}}$ .

Total water demand for irrigation can be projected  $n$  years into the future as follows:

$$\text{TWD}_{\text{IRRIGATION},t} \times (1 + \phi)^{\hat{n}} \quad (8.3)$$

<sup>a</sup> Note that, in a strict theoretical sense, the “total consumptive water use” in crop production is different from “total water applied” and “total water applied to the crop” is also different from “irrigation dosage.” This is explained in [Annexure 1](#).

where  $t=0$  (year),  $\emptyset$  = annual compound growth rate of the population (fraction),  $n$  is the numbers of years. If we are considering 2025 as the year for demand projections,  $n$  will be 14.

While estimating irrigation water demand, losses in nonrecoverable deep percolation and soil evaporation have been considered. It has been assumed, however, that there is no percolation that contributes to return flows to groundwater systems or stream channels, given the arid climate and geohydrology of most of Pali district. The values of consumptive water use in irrigation and current irrigation water demand (amount to be applied in the field) work out to be same as a result, although they are conceptually different.

Available data from 2011 to 2012 show that wheat and mustard used 86% of the 417 MCM of water used by *rabi* crops, while, among *kharif* crops, irrigated cotton uses most (64%) of the 48 MCM used during the season (Table 8.1).

While estimating the irrigation demand at site,  $\Delta_{\text{IRRIGATION}, t}$  after  $n$  years, efficiency improvements can be assumed, which will affect TWD for irrigation as follows:

$$\text{TWD}_{\text{IRRIGATION}, t} \times (1 + \emptyset)^n \times \frac{\text{IE}_{\text{APPLICATION, CURRENT}}}{\text{IE}_{\text{APPLICATION, FUTURE}}} \quad (8.4)$$

**Table 8.1** Crop water demand, Pali district, 2011–12.

| Season       | Crop                 | Area under crop (ha) | Crop water requirement (MCM) | Crop water use <sup>a</sup> (MCM) | % to total agricultural water use in season |
|--------------|----------------------|----------------------|------------------------------|-----------------------------------|---------------------------------------------|
| Rabi         | Wheat                | 47,922               | 162.54                       | 203.18                            | 49                                          |
|              | Rapeseed and mustard | 34,880               | 119.72                       | 149.65                            | 36                                          |
|              | Cumin                | 14,665               | 17.6                         | 22                                | 5                                           |
|              | Gram                 | 6419                 | 17.34                        | 21.67                             | 5                                           |
|              | Barley               | 4163                 | 11.92                        | 14.9                              | 4                                           |
|              | Total                | —                    | 333.55                       | 416.94                            | 100                                         |
| Kharif       | Cotton               | 6261                 | 24.36                        | 30.45                             | 64                                          |
|              | Castor               | 1307                 | 8.25                         | 10.31                             | 22                                          |
|              | Chillies             | 464                  | 4.27                         | 5.34                              | 11                                          |
|              | Maize                | 462                  | 1.14                         | 1.42                              | 3                                           |
|              | Total                | —                    | 38.03                        | 47.54                             | 100                                         |
| Annual total |                      | —                    | 371.58                       | 464.48                            | —                                           |

<sup>a</sup>Including nonbeneficial evaporation and nonrecoverable deep percolation.

In the current estimation, water application efficiency is assumed to improve from 80% to 90%, over the 13-year period till 2025, which reduces the annual per-capita agricultural water demand from 228 m<sup>3</sup> in 2012 in to 202.7 m<sup>3</sup> in 2025. The total agricultural water demand for 2025 was estimated using the projected population of the district, i.e., 2.384 million persons (based on an estimated annual compounded growth rate of 1.13%) to be 483.3 MCM.

### 8.3.2 Domestic water demand

Per-capita domestic water demand is not likely to vary much between years, with variation in climate, and hence it is reasonable to assume that the per-capita water demand rate remains the same within shorter time horizons. A change in per-capita income could, however, drive up domestic water demand and this assumption should therefore be modified for longer time durations as the impacts could be significant. Here, domestic water demand considers only water demand for drinking and cooking, washing, and sanitation (bathing and toilet use).

$$\text{Per-capita domestic water demand} = (1 + \emptyset)^n \times \partial \times 365/1000 \quad (8.5)$$

where  $\partial$  is the average daily per-capita domestic water use (in liters) and  $\emptyset$  is the income elasticity of domestic water demand (expressed as a ratio of the increase in domestic water demand per annum against a 1% increase in per-capita annual income).

Assuming a per-capita water demand of 70 lpcd in rural areas and 140 lpcd for urban areas, and an estimated rural population of 1.813 million persons and urban population of 0.578 million persons, the 2025 demand for water for domestic uses in rural and urban areas was estimated to be 46.33 and 29.52 MCM, respectively. This represents a total domestic water demand of 75.85 MCM for Pali district in 2025.

### 8.3.3 Livestock water demand

Livestock water demand for direct consumption is a function of the animal body weight, feed,<sup>b</sup> ingested salt, lactation, ambient temperature, and an animal's genetic adaptation to its environment. The amount of water

<sup>b</sup> This is a function of animal body weight.

required by a unit of livestock for direct consumption increases with an increase in daily dry matter intake (kg) and, in the case of milch animals, the average daily milk yield (liters), as well. Accordingly, small ruminants such as goat and sheep require less water as compared to large livestock such as camels, buffaloes, and cows. Lactating animals would, however, require more water for consumption than dry animals. For example, indicative water intake by dairy cows could be estimated by the following equation (after Pallas, 1986):

$$Y = 16.0 + 0.71 i + 0.41 m + 0.05 S + 1.2 T \quad (8.6)$$

where  $Y$  is the daily water intake (in liters, assuming 1 L of water weighs 1 kg),  $i$  is the daily dry matter feed intake (kg/day),  $m$  is the daily milk production (kg/day),  $S$  is the sodium intake (g/day), and  $T$  is the mean weekly minimum temperature.

Indicative water requirements for different types of livestock (per tropical livestock unit or TLU) are in Table 8.2, which also gives normal figures of animal body weight and the TLU they constitute. Actual water requirements of these livestock need to be worked out based on the actual body weight of the animals, by using the voluntary daily water intake for that category of animal per TLU. For instance, for a buffalo with a body weight of 400 kg, the water requirement would be  $38.6$  (per unit of cattle)  $\times 400/250$ , i.e., 77.2 L per day.

Future livestock water demand can be estimated using the observed past annual compounded growth rate of livestock population for each category of livestock, and the population.

**Table 8.2** Indicative water requirements for different types of livestock.

| Livestock type | Mean live weight (kg) | Tropical livestock units per head | Voluntary daily water intake by season and average temperature (L/TLU) |        |      |      |          |
|----------------|-----------------------|-----------------------------------|------------------------------------------------------------------------|--------|------|------|----------|
|                |                       |                                   | Daily dry matter intake                                                |        |      |      |          |
|                |                       |                                   | kg                                                                     | kg/TLU | Wet  | Dry  | Dry, hot |
| Camel          | 410                   | 1.60                              | 9                                                                      | 5.60   | 9.4  | 21.9 | 31.3     |
| Cattle         | 180                   | 0.70                              | 5                                                                      | 7.00   | 14.3 | 27.1 | 38.6     |
| Sheep          | 25                    | 0.10                              | 1                                                                      | 10.00  | 20.0 | 40.0 | 50.0     |
| Goat           | 25                    | 0.10                              | 1                                                                      | 10.00  | 20.0 | 40.0 | 50.0     |
| Donkey         | 105                   | 0.40                              | 3                                                                      | 7.50   | 5.0  | 27.4 | 40.0     |

Source: FAO online catalog on water for animals, based on Pallas, P., 1986. Water for Animals. Food and Agriculture Organization, Rome.

The total livestock water use in Pali district was estimated to be  $7.87 \text{ m}^3$  per annum in 2007 (the latest year for which data on livestock population were available).<sup>c</sup> Assuming that in the future that per-capita livestock, the size of holding, the composition of livestock, and water use efficiency in livestock and dairy production remain the same, and hence using only population as a driver of livestock water demand projection, the total water demand for livestock in Pali district for 2025 was estimated to be 18.774 MCM, using the following calculation:

$$\text{TWD}_{\text{LIVESTOCK 2025}} = \text{Per-capita livestock water use}_{2007} \times \text{Population}_{2007} \times (1.0113)^{18} \quad (8.7)$$

### 8.3.4 Industrial water demand

The major industries of Pali district are cement plants, textile industries, and small industries. But, in Luni basin, there is a thermal power plant (located near Barmer), having a capacity of 250 MW. The total water consumed in thermal power plants for 1 h of operations (i.e., for 1 MW of power generated) is in the range of  $3.5 \text{ m}^3$  per MW of installed capacity. This, however, is only 10% of the total water required for various uses in thermal power plants. The water requirement for different types of industries, excluding thermal power plants, is given in Table 8.3.

The total water demand for industrial production can be estimated based on the total volume of production and the water consumption per unit of production. Total industrial water demand per annum can be estimated as

$$(\text{TWD}_{\text{INDUSTRY}}) = \sum_{i=1}^n V_{\text{PRODUCTION}, i} \times \phi_i \quad (8.8)$$

where  $V_{\text{PRODUCTION}, i}$  is the volume of production for the industry type,  $i$  and  $\phi_i$  is the water consumption per unit of production for industry type  $i$ . Given the water consumption per unit of production for any of the 17 industrial types (i.e., from Table 8.3) and, the total volume of output for that industry is known, the annual water demand can be calculated.

Unfortunately, however, data on the quantum of industrial outputs produced (like the total amount of cement, textiles, chemicals, etc.) under each

<sup>c</sup> See details of the livestock population in Annexure 2.

**Table 8.3** Industrial production, water use per unit for selected industrial sectors (1996–97).

| Category of industry                | Water requirement (m <sup>3</sup> )/<br>ton/year (Ø) |
|-------------------------------------|------------------------------------------------------|
| Integrated iron and steel           | 22                                                   |
| Smelters                            | 82.5                                                 |
| Petrochemicals and refinery         | 17.0                                                 |
| Chemicals—caustic soda              | 5.5                                                  |
| Textile and jute                    | 20                                                   |
| Cement                              | 4.5                                                  |
| Fertilizer                          | 16.7                                                 |
| Leather products                    | 30                                                   |
| Rubber                              | 6.6                                                  |
| Food processing                     | 6.8                                                  |
| Inorganic chemicals                 | 200.0                                                |
| Sugar                               | 2.2                                                  |
| Pharmaceuticals                     | 25.0                                                 |
| Distillery (requirement per 1000 L) | 22.0                                                 |
| Pesticides                          | 6.5                                                  |
| Paper and pulp                      | 200.0                                                |
| General engineering                 | 2.2                                                  |
| <i>Total</i>                        | 669.5                                                |

Source: GOI (1999) Integrated Water Resources Development: A Plan for Action, Report of the National Commission on Integrated Water Resources Development.

manufacturing type are not available for the districts falling in the basin. An alternative approach had therefore to be used, taking estimates of total industrial water demand for India (available in Kumar (2010) for the period from 2000 to 2025). This gives a total industrial water demand in the country in 2010 of 23.955 BCM, and an average per-capita industrial water demand for the country of 19.5 m<sup>3</sup> per annum. Noting that Seckler et al. (1998) used a per-capita industrial water demand of 40 m<sup>3</sup> per annum for the work on global water supply-demand estimates, a modest figure of 20 m<sup>3</sup> per capita has been assumed for Pali district. Total industrial water demand for 2025 was thus estimated to be 47.7 MCM.

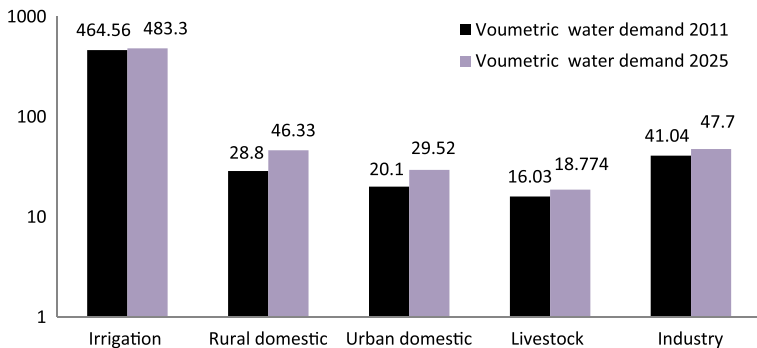
### 8.3.5 Summary of water demands

The total water demand in Pali district is estimated to be 570.53 MCM in 2011 and projected to rise to 625.62 MCM by 2025 (Table 8.4 and Fig. 8.1).

**Table 8.4** Current and projected sectoral water demands (MCM).

| Sector                                                        | Water use at site (2011)   | Demand in 2025 |
|---------------------------------------------------------------|----------------------------|----------------|
| Irrigated agriculture                                         | 464.56                     | 483.30         |
| Per-capita irrigation water demand (m <sup>3</sup> per annum) | 228.00                     | 202.67         |
| Rural domestic                                                | 28.80                      | 46.33          |
| Per-capita (domestic): lpcd                                   | 50.0                       | 70.00          |
| Urban domestic (MCM)                                          | 20.10                      | 29.52          |
| Per-capita (urban domestic)                                   | 100.0                      | 140.00         |
| Industry                                                      | 41.04                      | 47.70          |
| Per-capita industrial water demand                            | 20 m <sup>3</sup> /annum   |                |
| Livestock                                                     | 16.03                      | 18.774         |
| Per-capita livestock water use                                | 7.87 m <sup>3</sup> /annum |                |
| <i>Total</i>                                                  | 570.53                     | 625.62         |

Authors' own estimates based on Seckler, D., Amarasinghe, U., Molden, D., de Silva, R., Barker, R., 1998. *World Water Demand and Supply, 1990 to 2025: Scenarios and Issues*, Research Report 19, International Water Management Institute, Colombo, Sri Lanka; Kumar, M.D., 2010 *Managing Water in River Basins: Hydrology, Economics, and Institutions*, Oxford University Press, New Delhi; and Census 2001 and Census 2011, and analysis of secondary data, FAO CROPWAT estimates of crop PET.

**Fig. 8.1** Current and future water demand in different sectors (2025): Pali district (MCM).

## 8.4 Analyzing water supply

Arriving at a district IWRM plan requires balancing all water demands within the district against the utilizable supplies from various surface and groundwater sources. Not all the water available in a basin or administrative unit can be utilized, whether surface water or groundwater. The first task therefore is to get reliable data on utilizable surface and ground water.

### 8.4.1 Surface water resources

Estimating stream flows based on simple rainfall-runoff relations can lead to large errors when the interannual variability in rainfall is excessively high and that the runoff coefficient itself changes drastically with quantum of rainfall. In many arid tropics, assessing surface runoff in small river basins is a difficult task, as these basins are not gauged. One reason for this lack of attention to small basins is that most of these rivers are ephemeral and, in most years, do not have any discharge. The Luni river basin has only two gauging points, maintained by the Central Water Commission (CWC), at Balotra and Gandhav, both of which fall outside Pali district.

An alternative approach is needed therefore to estimate surface water availability. One approach involves estimating runoff from rainfall data using the US Soil Conservation Bureau's curve number method, which uses rainfall infiltration rates, based on the soil type, vegetation cover of the soil, and the antecedent moisture. Since the daily rainfall data are available for a large number of stations within the district, runoff for each rainfall event occurring during the monsoon in a year can be estimated using data on land use and land cover available for the area, corresponding to each year. The stream flow series can thus be generated using the historical data of rainfall and land use for each year, the dependability curve for the runoff can be estimated using these data, and "dependable yield" from the catchment can be worked out corresponding to different degrees of dependability. The rainfall-runoff relationship can be estimated, based on the estimated stream flow series and the weighted average of the annual rainfall, for areas with similar rainfall pattern, land use, soil, and climate in the basin or adjoining basins.

The other approach is to estimate the rainfall-runoff relation for the "basin as a whole" using the "estimated annual virgin flows for the basin," and the annual (spatial) average rainfall, and subsequently applying the same for the district of Pali, for the rainfall it receives in each year.

$$\text{Virgin flow VF} = \text{RUNOFF}_{\text{OBSERVED}} + \text{WD}_{\text{EFFECTIVE}} \quad (8.9)$$

where  $\text{WD}_{\text{EFFECTIVE}}$  is the effective water diversion, or the total amount of water diverted from the main channel and tributaries in the basin, through various water-impounding structures, which is the sum of the water releases from reservoirs to meet various demands, water evaporated from the reservoirs, and the water remaining in storages at the end of the year from the impounded water, minus the return flows from various demand sites to the stream channels.

For river basins such as Luni, there are several small water harvesting structures in Pali district and other districts of the basin, which are in the upper catchment areas. While estimating virgin flows, it is important to account for the water impounded by these structures. Though these small water bodies generally do not divert any water for any uses, some water percolates from these reservoirs and a significant amount of water evaporates. Therefore, if data are available, it would be advisable to incorporate this in the estimation of virgin flows.

The average annual rainfall of the basin can be estimated by taking the weighted average of the point rainfalls using the Thiessen Polygon method as the rainfall gradient across the basin is not very sharp. However, when the gradient of isohyets is sharp, the area between two rainfall isohyets should be estimated and multiplied by the average of the rainfall values represented by the isohyets.

The utilizable yield is to be calculated from the dependable yield. This would depend on the topographical conditions and the technology used for harnessing water, but the actual amount of water that can be tapped depends on the committed flows downstream. For instance, although the district catchment might have a dependable yield of “**X**” MCM per annum, there could be a reservoir downstream of the catchment (designed for a dependable yield of **0.50 X**) but falling outside the district boundary, which depends on inflows received from the upper catchment. This means that the total amount of water that can be utilized from the district catchment would only be just half the total dependable yield of the district catchment. A further possible reduction is on account of conveyance losses (see [Annexure 3](#) for details).

To estimate the surface water potential in the district, the rainfall-runoff relationship estimated for the basin is used in conjunction with the average of the mean annual rainfall values for the rain gauges of Pali district.

First, from point rainfall data from nine rain-gauge stations in Pali, the weighted average of the rainfall was estimated for 41 years for which data were used (1971–2012)—which shows considerable variability ([Fig. 8.2](#)).

Next, the rainfall probability curve was plotted ([Fig. 8.3](#)) to map rainfall with a probability of occurrence of 3 in 4 years (75% probability of occurrence) and 6 in 10 years (60% probability).

Finally, rainfall with dependability of occurrence of 75% was estimated to be 318 mm and that with dependability of 60% was estimated to be 355 mm, but the average rainfall of 2011–12 (639.77 mm) was used, however, to estimate the utilizable runoff from the district as 109.26 MCM.

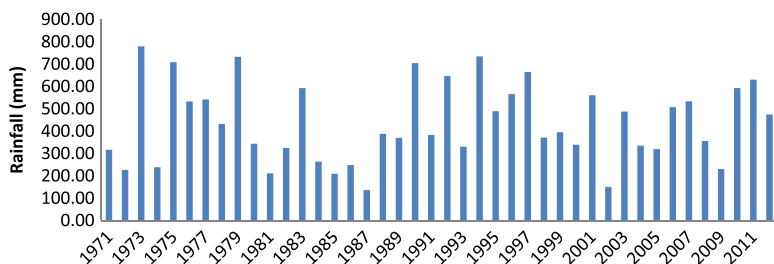


Fig. 8.2 Average rainfall in Pali district: 1971–2012.

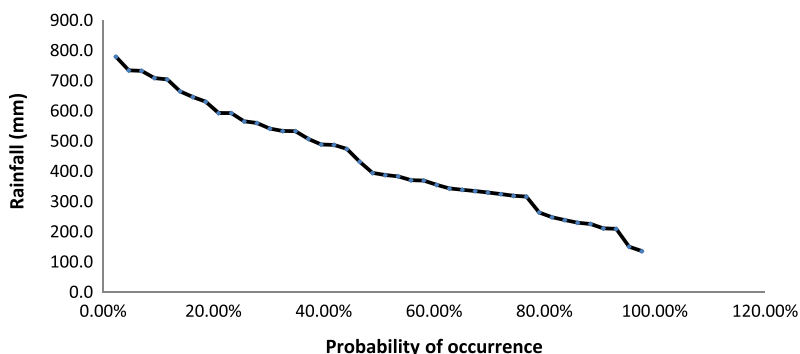


Fig. 8.3 Rainfall probability curve for Pali district.

## 8.4.2 Groundwater resources

Groundwater resources in western Rajasthan occur mostly in alluvial and sedimentary formations. All this water can be safely abstracted, as the groundwater flow gradients in the region are not steep and the groundwater outflows into natural streams are insignificant. In addition to the renewable groundwater resources, the region also has significant amount of static groundwater resources. Estimates of total amount of renewable groundwater resources in the district are readily available, as are data on the total amount of groundwater resources in the basin.<sup>d</sup>

Groundwater resources in both Luni basin and Pali district are fully developed at present (Rolta report). The wells and water abstraction devices available in the district of Pali can pump out more groundwater than what is permissible under sustainability considerations—as evidenced by current

<sup>d</sup> Tahal Consultants' Report on water resources in Rajasthan, Vol. 3.2.

abstraction rates prevailing in the basin and the district. If further depletion of groundwater is stopped, in deference to the sustainable development criteria, the amount of groundwater that can be tapped from the aquifers of the region would be just equal to or less than the renewable groundwater resources.

The total groundwater stock in the basin is around 10,500 MCM, in addition to an annual renewable groundwater resource of 2000 MCM. Pali district also has some groundwater stock. Therefore, if long-term sustainability of the aquifer is allowed to be compromised and aquifers allowed to deplete at the current rate, the amount of groundwater that can be tapped for various uses in Pali district and Luni basin would be equal to the current rate of withdrawal.

$$\begin{aligned} \text{Permissible level of abstraction} &= \text{GW}_{\text{ABSTRACT, ANNUAL}} \\ &= \text{GWR}_{\text{RENEWABLE, ANNUAL}} + \left( \frac{\text{GW}_{\text{STOCK}}}{n} \right) \end{aligned} \quad (8.10)$$

where  $n$  is the number of years for which the aquifer can be pumped at the current rate;  $\text{GW}_{\text{STOCK}}$  is the total groundwater stock; and  $\text{GWR}_{\text{RENEWABLE, ANNUAL}}$  is the annual groundwater recharge.

Estimating the available renewable groundwater requires an understanding of the groundwater balance, with inflows and outflows. Annual groundwater replenishment (groundwater inflow) in an area can have three components:

1. Recharge directly from precipitation and from local water storage structures
2. Recharge from local water bodies after the monsoon season, when natural recharge from rainfall becomes negligible; and
3. Artificial recharge from recharge schemes.

Groundwater outflows during monsoons include pumping during the season, the net of lateral inflows and outflows (outflow-inflow). The basis for the estimation of groundwater balance is the change in storage, which can be measured through water-level fluctuations. The groundwater balance equation can thus be written as:

$$\begin{aligned} \Delta_{\text{STORAGE}} &= \text{RECH}_{\text{MONSOON}} + (\text{INFLOW}_{\text{LATERAL}} - \text{OUTFLOW}_{\text{LATERAL}}) \\ &\quad - \text{PUMP}_{\text{MONSOON}} \end{aligned} \quad (8.11)$$

$$\Delta_{\text{STORAGE}} = \text{WLF}_{\text{POST-PRE}} \times S_y \quad (8.12)$$

where  $WLF_{POST-PRE}$  is the difference in depth to water level between pre-monsoon and postmonsoon periods and  $\Delta_{STORAGE}$  is the net storage change during monsoon.

Given the topography of the study area, lateral flows can be significant and hence are considered in the estimation of net recharge.

$$RECH_{MONSOON} = WLF_{POST-PRE} \times S_y + PUMP_{MONSOON} \quad (8.13)$$

Note that since whatever recharge occurs from the surface water bodies during June to October is already captured in the water level fluctuation in the wells, there is no need to estimate separately the recharge from water bodies for the monsoon season. Note also that  $RECH_{MONSOON}$  as defined in Eq. (8.13) includes recharge from natural water bodies and artificial recharge schemes and thus, to estimate the recharge from rainfall alone (Components 1 and 2 above), the artificial recharge component will have to be segregated.<sup>e</sup>

Available estimates of utilizable groundwater resources in Pali district show that the gross groundwater draft exceeds recharge by 68 MCM annually in the district (Table 8.5).<sup>f</sup>

Though the blockwise estimates of static groundwater resources for Pali show a very modest figure of 47.77 MCM for the whole district, the estimates based on basin and sub-basin wise figures of groundwater resources show a much higher figure of 1242.88 MCM. Given that the rainfall of Pali district is comparatively higher than that of the rest of Luni basin, and that most of Pali district is underlain by deep alluvial formations, the latter figures appear to be more realistic, and therefore used. As per the 2009 estimates of Central Ground Water Board (CGWB), the net utilizable groundwater resource in Pali district is 302.06 (break up not available), considering the recharge during nonmonsoon period and ground water discharge (Government of India, 2011). Since these are more recent estimates (done for 2009), they have been used in the present analysis.

<sup>e</sup> To estimate the recharge from artificial recharge structures, a new method (double difference) must be employed, wherein the water-level fluctuation in two localities (receiving almost the same amount of rainfall)—one WITH recharge structure and the other WITHOUT the recharge structures—are considered and the difference in the average (pre- and postmonsoon) water-level fluctuation taken. This is to nullify the effect of natural recharge on water levels and disaggregate the effect of the structures. The same approach can be used to estimate the recharge from the structures postmonsoon.

<sup>f</sup> Estimates taken from the Report of Tahal Consultants.

**Table 8.5** Static and dynamic groundwater resources of Pali district (2005–09).

| Name of the block | Net groundwater availability (MCM) | Gross groundwater draft (MCM) | Static groundwater resources (MCM) |
|-------------------|------------------------------------|-------------------------------|------------------------------------|
| Pali              | 38.63                              | 45.95                         | 5.01                               |
| Desuri            | 22.65                              | 28.67                         | 2.70                               |
| Jaitaram          | 53.91                              | 72.95                         | 11.63                              |
| Marwar junction   | 38.01                              | 55.86                         | 6.71                               |
| Pali              | 8.48                               | 7.63                          | 1.25                               |
| Raipur            | 20.22                              | 27.25                         | 3.78                               |
| Rani              | 28.08                              | 31.56                         | 2.94                               |
| Rohat             | 5.96                               | 5.56                          | 0.68                               |
| Sojat             | 30.97                              | 40.3                          | 5.63                               |
| Sumerpur          | 32.51                              | 31.72                         | 7.44                               |
| <i>Total</i>      | 279.42                             | 347.45                        | 47.77                              |

Source: Study on Planning of Water Resources Planning of Rajasthan, Draft Final Report submitted to the State Water Resources Planning Dept., Government of Rajasthan, December 2013, Vol. 3.2, 2c

**Table 8.6** Available water supplies from surface and underground sources.

| Water source            | Renewable supplies per annum (MCM) | Static fresh groundwater resources in Pali district (MCM) <sup>a</sup> |
|-------------------------|------------------------------------|------------------------------------------------------------------------|
| Surface water (2011–12) | 109.26                             | 1242.88                                                                |
| Groundwater (average)   | 302.03                             |                                                                        |
| Total water resources   | 411.29                             |                                                                        |

<sup>a</sup> Own estimate based on available estimates of groundwater in sub-basins falling even partly in the district.

### 8.4.3 Summary of water supplies

The total utilizable water resources that can be used to meet the demands in the district (based on 2011–12 estimates) are 411.29 MCM, per annum (Table 8.6). While around 75% of the 411 MCM of total annual renewable water supplies are groundwater, Pali also has around 1240 MCM of static fresh groundwater resources.

## 8.5 Balancing demand and supply

District IWRM planning involves deciding on a variety of water management interventions in water supply (water resource development, water imports, etc.) and water demand (water use efficiency improvement plans)

in the district, so that future demands for water in the district—at the aggregate level and for individual sectors—can be met from utilizable future water supplies. While future water supplies can come from either within the district or from outside the district (but within the basin), interventions for water use efficiency improvements must come from within the district. This should, however, be done such that the integrity of the hydrological system (aquifers, stream flows) is not threatened in the long run, while simultaneously ensuring that there are no undesirable consequences for uses and users in other parts of the basin. It is, therefore, necessary that the analysis is done at both spatial and temporal scales, where the different types of interactions of the hydrological system and the interaction between hydrological system and water use systems are well integrated in the analysis of demand and supply balances.<sup>8</sup> Based on the estimated future supply-demand balance for water in the district, the nature and degree of water problems, in terms of both quantity and quality, can be identified.

### 8.5.1 Water availability-demand gap

Against the total renewable water availability of 411.3 MCM in 2011–12, the district consumed around 465 MCM of water for irrigation alone, nearly 90% of which is during the winter *rabi* (winter) season (Table 8.7).

**Table 8.7** Agricultural water demand and water availability, Pali district, 2011–12 (MCM).

|                                    |     |       |     |
|------------------------------------|-----|-------|-----|
| Total renewable water availability |     |       | 411 |
| Groundwater resources              | 109 |       |     |
| Surface water runoff               | 302 |       |     |
| Total water demand                 |     |       | 570 |
| Total agricultural water demand    |     | 465   |     |
| <i>Rabi</i> irrigation             | 417 |       |     |
| <i>Kharif</i> irrigation           | 48  |       |     |
| Total domestic water demand        |     | 48.90 |     |
| Total livestock water demand       |     | 16.03 |     |
| Total industrial water demand      |     | 41.04 |     |
| Demand-availability GAP            |     |       | 159 |

<sup>8</sup> The Water Evaluation and Planning (WEAP) system is a user-friendly water balance model that can be used for water resource assessment and basin planning. The water supply-demand balance for any geographical unit can be set up using WEAP model, and the same can be integrated into the basin in which the district falls.

Table 8.7 shows that, even in 2011–12, agricultural water demand is more than 80% of total water demand and total water demands exceeds supplies by 159 MCM: Clearly the district is not able to meet all its water requirements for domestic and productive uses from the available, renewable water resources in the basin. The deficit is currently being met through groundwater mining, but it is quite unlikely that the static groundwater resources in the district (1248 MCM) will be able to sustain the mining—which is currently occurring at the rate of 68MCM per annum—till 2025.

It must, however, be kept in mind that (1) utilizable water supplies can change drastically from a wet year to a dry year and (2) the area under irrigated crops can reduce significantly, thereby affecting major reductions in the actual demand for water. Hence, the analysis will have to be carried out for a long period of time, considering climatic variations and resource dynamics.

Since water demand is projected to increase to around 625 MCM by 2025 (see Table 8.4), and assuming no change in supplies, the current gap of 159.20 MCM will also increase to 214.30 MCM by 2025. Some potential interventions to meet the deficit are discussed now.

### 8.5.2 Water management interventions

These interventions are suggested based on a consideration of the following: hydrological regime such as rainfall, aquifer conditions, stream flows, and occurrence of hydrological extremes; socioeconomic conditions, viz., cropping pattern, irrigation pattern, and consumptive water use in agriculture and other sectors; climatic conditions; and overall water situation in the region.

- *Rejuvenation of tanks and ponds:* This will impact the supply side of the water balance and therefore will be reflected as an increase in storage capacity of the supply reservoir. Since this essentially will have to come from the natural catchments, it would mean reduction in downstream flows.
- *Construction of (traditional) water bodies:* Traditionally designed water harvesting structures (such as *tankas* and *beris*) will either capture rainfall runoff or be linked to surface water sources such as canals (in the case of IGNP) or streams. These will have to be incorporated into a water allocation model like WEAP as new supply reservoirs (nodes).
- *Groundwater banking:* The loamy sand, the geological strata dominated by recent and old alluvium, high aridity, and depleted aquifers offer ideal conditions for artificial recharge of groundwater. The vast amount of land

available in the region, which is not cultivated, can be used as infiltration beds. The only constraint is the availability of a dependable source of water for recharge. But, the excess flow available in Luni in very wet years could be a good source of water for recharge. These excess flows could be used for groundwater banking in empty aquifers. Impact of recharge schemes will be on the resource availability and therefore will have to be affected in the estimates in terms of a return flow link to groundwater. Here, the major input will be rate of infiltration of water (which will be shown as a demand site return flow link in a WEAP model). The major sources of water from within the basin or from outside, which can be used for recharging the aquifers, need to be identified.

- *Urban piped water leakage prevention:* A large amount of water is wasted in urban water distribution systems through leakage, and the volume of leakage is a function of age of the infrastructure, length and pressure maintained in water distribution lines. Leakage reduction in urban water systems is an integral part of urban water management, which can not only help defer the investment required to augment the supplies, but also save water. This can be reallocated to other uses within the district or basin. But such measures should be resorted to only when the cost of leakage reduction, i.e., the cost of saving a unit volume of water through leakage reduction measures, is lower than the cost of production of new water source through conventional approaches, which includes the resource cost, the cost of infrastructure to develop and supply, and the environmental degradation cost. Intuitively, in water-scarce regions, the resource cost and the cost of environmental degradation would be high, thereby justifying such investments.
- *Microirrigation and mulching:* Research in north Gujarat has shown that microirrigation and mulching reduced irrigation water used (cubic meters per hectare) by 22%–80% of the original water use in a range of row crops (for more details, see [Annexure 4](#)).

### 8.5.3 Scale effects and economic viability

In order to determine the level at which some of the aforementioned water management interventions (schemes) should be implemented to address the problems that are likely to emerge in future, future scenarios of water balance need to be generated with a variety of potential interventions with different scales. These can be compared against the “base case scenario” of water balance to see the impact of different types of interventions on the

overall demand-supply scenario and the resource condition. Scenarios, which produce the highest impact in terms of reducing the demand-supply gap and which have a positive impact on the resource condition (stream flows and groundwater regime) need, can be shortlisted.

Planning of integrated water management interventions cannot also be decided based on only the physical impacts of these potential interventions on future water supplies and demand: The economic viability of these interventions also needs to be examined. In order to identify cost-effective options, their costs per unit must be calculated and compared against potential benefits. Often, however, such information is not readily available. In such situations, these must be generated through heuristic economic analysis. Some key unknowns in such analysis are:

- The cost of harvesting a unit volume of water through traditional and modern techniques (e.g., water harvesting structures or *tanka* systems) against the economic value of the harvested water. In the case of large water-impounding structures, however, it is important to consider only the net hydrological gain, as there could be negative impacts of such interventions downstream.
- Cost of drip irrigation per unit area of crop, against the economic value of water saved from unit area and the incremental benefit from the use of drip irrigation.
- Cost of mulching per unit area of the crop, against the economic value of water saved from unit area and the incremental benefit from the use of mulching systems.
- The net benefit of rejuvenating traditional water bodies, against the those of alternatives.
- Cost of artificial recharge for “groundwater banking” in very wet years against the cost of getting freshwater for domestic water supply in rural and urban areas during water scarcity.

This additional analysis can modify both the types and scale of interventions in individual Gram Panchayats (GP) as well as for the district as a whole: For instance, the area under microirrigation for different crops, area under mulching for different rain-fed crops, the area under cultivation, the number of recharge schemes, the number of *tankas*, number of tanks and ponds to be rejuvenated, may change—and some may also be dropped, based on their impact on the overall model outcomes vis-à-vis stream-flows, groundwater recharge, and water balance.

Further, based on the overall impact at the district level, the GP-level IWRM plans may have to be adjusted and revised (Fig. 8.4).

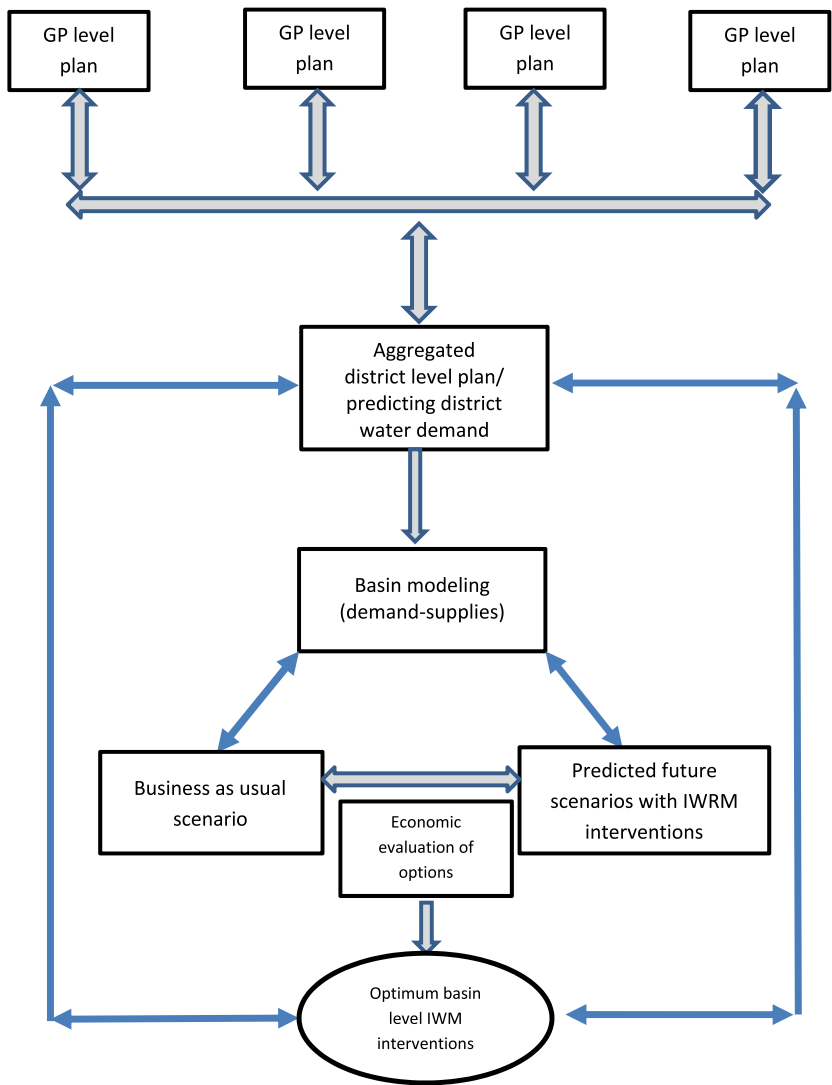


Fig. 8.4 Decision-making framework for district IWRM planning.

### 8.6 District water management options

There is little scope to eliminate the demand-availability gap in Pali district by reducing either domestic or industrial water consumption, as the overall water consumption in these sectors is much lower than that in agriculture—which is around 80% of total water demand (Table 8.7). Outside of bringing

**Table 8.8** Potential impact of drip irrigation on row crops in Pali district (100% coverage): 2011–12.

| Crop         | Irrigated area (ha) | Total water use under traditional methods of irrigation ('000 m <sup>3</sup> ) | Extent of reduction in water use (%) | Reduction in irrigation water use (MCM) |
|--------------|---------------------|--------------------------------------------------------------------------------|--------------------------------------|-----------------------------------------|
| Castor       | 1307                | 10,312                                                                         | 22                                   | 2.25                                    |
| Cotton       | 6261                | 30,451                                                                         | 51                                   | 15.50                                   |
| Chillies     | 464                 | 5336                                                                           | 69                                   | 3.69                                    |
| Fennel       | 1003                | 2462                                                                           | 30                                   | 0.73                                    |
| <i>Total</i> | 9035                |                                                                                |                                      | 22.17                                   |

Source: Based on Kumar, M.D., 2010. Managing Water in River Basins: Hydrology, Economics, and Institutions, Oxford University Press, New Delhi and INCID, 1994. Drip Irrigation in India. Indian National Committee on Irrigation and Drainage, New Delhi.

water from other river basins, two clear options to close the deficit by 2025 are (1) expand microirrigation and mulching and (2) restrict further increases in irrigated area.

### 8.6.1 Expand microirrigation and mulching

If all the crops that are amenable to drip irrigation are covered under micro-irrigation systems in the entire district, the impact in terms of reduction in water demand would be around 22 MCM (Table 8.8).

The analysis assumes that (1) all the water used for irrigation (which is only 10% higher than the ET demand) eventually gets depleted and (2) the use of drip irrigation for these row crops reduces nonbeneficial evaporation (of water from the soil not covered by canopy) and nonrecoverable deep percolation, thereby achieving “real or wet water saving.”<sup>h</sup>

Plastic mulching for rain-fed *kharif* crops can give a potential “green water” saving of nearly 30 MCM per annum, given the current cropping pattern (Table 8.9).<sup>i</sup>

Even with the combined reduction of around 52 MCM, Pali will still not be able to meet all its domestic and productive water requirements from the available, renewable water resources in the basin (see Table 8.10).

<sup>h</sup> Seckler (1996) details the distinction between real water saving and notional water saving.

<sup>i</sup> Only crops with distant spacing between plants and between rows have been considered, and not crops such as wheat, pearl millet, sorghum, and maize.

**Table 8.9** Impact of plastic mulching on rain-fed crops in Pali district (2011–12).

| Crop         | Irrigated area (ha) | Effective increase in water availability (MCM) |
|--------------|---------------------|------------------------------------------------|
| Maize        | 17,622              | 8.81                                           |
| Groundnut    | 1353                | 4.80                                           |
| Castor       | 9548                | 0.50                                           |
| Cotton       | 990                 | 0.68                                           |
| Cluster bean | 30,320              | 15.20                                          |
| Overall      | 59,833              | 29.92                                          |

Source: Based on Xie, Z.-K., Wang, Y.-J., Li, F.M., 2005. Effect of plastic mulching on soil water use and spring wheat yield in arid region of Northwest China, *Agric. Water Manag.*, 75, 71–83.

**Table 8.10** Water management scenarios for the district: 2011–25.

| Gap between demand and renewable, annual utilizable supplies       | Demand-supply gap |      |
|--------------------------------------------------------------------|-------------------|------|
|                                                                    | 2011              | 2025 |
| Under the “base case” scenario                                     | 159               | 214  |
| With drip irrigation technology (for row crops)                    |                   | 192  |
| With plastic mulching (for rainy season crops) and drip irrigation |                   | 162  |

### 8.6.2 Reduce irrigated area

This option is especially for crops that are not amenable to pressure irrigation systems and mulching. The availability–demand gap of 159.20 MCM by 2025 can be achieved in either of two ways:

- *Without expanding pressure irrigation and mulching*, through a 45% reduction in the area under both wheat and mustard grown using conventional methods of irrigation.
- *With expansion of pressure irrigation and mulching wherever possible AND* reducing the areas under irrigated wheat and mustard by about 30%.

This assumes of course that the demand for water in the agriculture and other sectors will not grow in the future, either due to population pressure or industrial growth—or that the availability decreases. If either of these happens and the gap widens, the area under major irrigated crops (mustard and wheat) may have to be reduced by 45% from current levels to close the gap.

Both options to bring future water demands in line with available water supplies require strong government-led action on (agricultural) water demand management, without which not only will the mining of static groundwater continue—to the detriment of future generations—but rising competition (and conflict) for increasingly scarce surface water resources will also affect poor and marginalized farmers adversely.

## Annexure 1: Water use hydrology of irrigation

Water use hydrology of irrigation is crucial in water resource planning as it affects not only water demand but also utilizable supplies of water (if water demands and supplies are considered on a reasonable time scale) due to the interactions between the irrigated fields and groundwater. Water use hydrology of irrigated field is complex, however, and depends on several factors including the method of irrigation, crop type, soils, climate, and the geohydrology. The interaction between surface water (irrigated fields) and shallow groundwater must first be defined, based on the extant irrigation practice. In the case of efficient irrigation technologies used for crops, the deep percolation to shallow aquifer can be assumed to be negligible. In the case of traditional methods of irrigation, however, the deep percolation rate can be reasonably assumed as the fraction in excess of the total water applied to the crop (which is the sum of soil moisture and the irrigation water applied) and the ET requirement of the crop.

$$DP_{RECH} = (\Delta_{APPLIED} - ET) \times F$$

where,  $\Delta_{APPLIED}$  is the sum of irrigation dosage and total soil moisture available from rainfall (also known as effective rainfall). For purely irrigated crops of winter and summer, the effective rainfall ( $P_{EFF}$ ) can be assumed to be zero.

$$\text{Water consumed in crop production} = \Delta_{APPLIED} - \{(\Delta_{APPLIED} - ET) \times F\}$$

In the case of deep groundwater table conditions (i.e., depth to water table exceeding 100 ft) in semiarid and arid climates, the value of  $F$  can be assumed to be zero, while in case of very shallow groundwater, the value can be assumed to be 1. In the latter case, real water saving from the use of microirrigation systems will be negligible.

$$\text{Maximum water saving from microirrigation} = \{(\Delta_{APPLIED} - ET) \times (1 - F)\}$$

## Annexure 2: Livestock population in Luni river basin (2007).

| Livestock<br>(2007) | Districts in Luni river basin |           |           |          |          |           |           |          |         | Total     |
|---------------------|-------------------------------|-----------|-----------|----------|----------|-----------|-----------|----------|---------|-----------|
|                     | Ajmer                         | Barmer    | Jalore    | Jodhpur  | Nagaur   | Pali      | Rajsamand | Sirohi   | Udaipur |           |
| Cattle              |                               |           |           |          |          |           |           |          |         |           |
| <i>Indigenous</i>   | 83,239                        | 1,48,441  | 2,43,273  | 95,454   | 43,089   | 3,50,186  | 24,166    | 81,685   | 12,976  |           |
| <i>Exotic</i>       | 4182                          | 99        | 262       | 5287     | 1651     | 4859      | 2174      | 374      | 273     | 19,161    |
| <i>Total cattle</i> | 87,420                        | 1,48,540  | 2,43,535  | 1,00,742 | 44,740   | 3,55,045  | 26,340    | 82,059   | 13,248  | 11,01,670 |
| Goat                | 1,71,924                      | 5,17,495  | 4,53,096  | 2,15,945 | 1,52,005 | 7,01,932  | 47,212    | 1,38,202 | 15,308  | 24,13,118 |
| Sheep               | 1,11,964                      | 3,19,494  | 5,24,083  | 1,50,419 | 85,129   | 9,24,553  | 11,718    | 1,01,108 | 2265    | 22,30,732 |
| Buffalo             | 74,990                        | 36,459    | 3,40,806  | 40,505   | 49,255   | 3,15,418  | 20,571    | 67,234   | 7332    | 9,52,571  |
| Pig                 | 4388                          | 969       | 2409      | 159      | 335      | 6505      | 182       | 0        | 19      | 14,965    |
| Camel               | 465                           | 13,692    | 6774      | 3908     | 1508     | 8289      | 234       | 2424     | 77      | 37,370    |
| Donkey              | 323                           | 4920      | 2977      | 765      | 256      | 2778      | 147       | 570      | 46      | 12,783    |
| Horse               | 125                           | 402       | 1362      | 91       | 128      | 1154      | 104       | 127      | 9       | 3502      |
| Pony                | 1                             | 0         | 0         | 0        | 2        | 12        | 0         | 0        | 0       | 15        |
| <i>Total</i>        | 4,51,600                      | 10,41,971 | 15,75,042 | 5,12,534 | 3,33,358 | 23,15,686 | 1,06,508  | 3,91,724 | 38,304  | 67,66,726 |

Source: Based on Livestock Census of Rajasthan 2007.

### Annexure 3: Conveyance losses in irrigation and piped water systems in Pali district

The amount of water to be supplied to meet the demand in a sector or in a locality could be higher than the actual “demand” at the site, because of the losses in conveyance of water. Thus, conveyance losses need to be considered in estimating water supply requirements. The total water supply requirement ( $WS_{REQ}$ ) can therefore be expressed as:

$$WS_{REQ} = W_{DEMAND} / (E_{CONV})$$

where  $E_{CONV}$  is the difference between the total amount of water supplied and the amount of water expected to be lost in conveyance for that level of water supply and supply schedules<sup>j</sup> against the total water supplied from the source, expressed as a fraction.

Such “losses” could be reusable depending on the local specific situation and characteristics of the water supply system.

Conveyance losses are generally low for groundwater-based irrigation systems, due to the short distance between the source and the point of demand (farmer’s fields) even when open channels are used to convey water. Losses are generally high in surface water-based canal irrigation systems due to the long distance between the reservoir/diversion structure and the command areas, and the high infiltration from the (generally large-sized) canals.

Rural domestic water supply systems are generally of two kinds in this region: those based on local groundwater sources, where water is supplied to the village where the source is located and pipelines are used for distribution of water to different settlements; and those where water is taken from a distant surface water source (either a large reservoir or a diversion structure or river/canal lift scheme) to many villages through pipelines. Conveyance losses are higher in the latter due to the large distance of water transport, compared to local groundwater-based schemes.

Conveyance losses in piped water supply systems are, however, bound to be less than that of large surface irrigation schemes that use canals. “Technical losses” in long-distance piped water distribution systems used in drinking water supply schemes are due to leakages (from cracks and joints), while nontechnical losses occur due to illegal tapping of water.

<sup>j</sup> Note that the conveyance loss will change with a change in supply volumes and supply rates.

Losses in canal-based water distribution and delivery systems used in surface irrigation schemes, however, could be from seepage (depending on the type of lining, i.e., whether open channel, brick lining, cement lining, or concrete lining) and evaporation.

Technical losses from water conveyance systems end up, in most cases, in natural water courses or groundwater systems or lakes from which the water can be regained. Sometimes, however, this water can also end up in the sea/oceans or saline formations—like the Great Rann of Kachchh (in the case of Luni river) or the Little Rann of Kachchh (in the case of Banas river)—from where it cannot be recovered.

Ideally, in the case of irrigation water supply, the supply requirement needs to be estimated based on the demand at site and conveyance efficiency. In Pali district, however, groundwater is the major source of irrigation and only a miniscule area is under canal irrigation. Also, farmers using well irrigation do not use long open channels for conveyance as their wells are close to their plots. And since they use rubber and plastic (HDPE and PVC) pipes due to water scarcity, the conveyance efficiency is close to 100%.<sup>k</sup>

## **Annexure 4: Microirrigation and mulching**

### **Microirrigation**

The use of microirrigation (MI) systems (e.g., drips and sprinklers) as well as plastic mulching for water demand management will reduce water application rates for irrigated crops. Necessary modifications will, however, have to be made in the return flow fraction since the deep percolation rate under MI will differ from that of traditional irrigation methods.<sup>l</sup>

Row crops for which drip system can be used in the region are castor, groundnut, tomato, onion, maize, and cluster bean, and the total area under irrigated crops that are amenable to MI system needs to be assessed. In order to apply water saving technologies as a new intervention in the water balance model (e.g., WEAP), and to assess their impacts on overall water balance,

<sup>k</sup> Another important issue to be noted and resolved is that even when the conveyance losses are significant (like in gravity irrigation systems), there are dangers of factoring in the “conveyance efficiency” to arrive at the supply requirement. This is because such an approach can overestimate the supply demand gap in a “static analysis,” as the return flows to groundwater or to the stream flows contributed by the “seepage losses” are not factored in the estimation of resource availability, which leads to underestimation of the supplies.

<sup>l</sup> This rate was imputed from data available from research in Rajasthan on the water saving impact of microirrigation.

it is important to know the physical impacts of these technologies. Research in north Gujarat has shown that drip irrigation reduced irrigation water used (cubic metres per hectare) by 22%–80% of the original water use in a variety of crops (see [Table A4.1](#)).

## Mulching

The impact of mulching on water demand in rain-fed crops is in terms of reduced soil evaporation (E) values of these crops and an increase in the total water available to meet the transpirative demands from the soil profile ([Xie et al., 2005](#)). With mulching, the water demand of the crop would be equal to transpiration instead of evapotranspiration. In terms of demand calculation, it means that the supplementary irrigation dosage can be reduced. Row crops, which are amenable to mulching, and which are grown during the rainy season in the district, need to be identified. In order to assess the potential impact of mulching on water balance, we look at the extent of

**Table A4.1** Potential change in irrigation water use for different crops after adoption of MI.

| Season  | Crop                | WST       | Irrigation water use (m <sup>3</sup> /ha) |                        |          |
|---------|---------------------|-----------|-------------------------------------------|------------------------|----------|
|         |                     |           | Before adoption of WSTs                   | After adoption of WSTs | % change |
| Monsoon | Cluster bean        | Sprinkler | 2549                                      | 1305                   | 49       |
|         | Castor <sup>a</sup> | Drip      | 4160                                      | 3250                   | 22       |
|         | Groundnut           | Sprinkler | 5603                                      | 5258                   | 6        |
|         | Chili               | Drip      | 11,500                                    | 3540                   | 69       |
|         | Eggplant            | Drip      | 5967                                      | 1180                   | 80       |
|         | Green gram          | Drip      | 840                                       | 540                    | 36       |
|         | Cotton              | Drip      | 7151                                      | 3510                   | 51       |
|         | Fennel              | Drip      | 2455                                      | 1728                   | 30       |
| Winter  | Potato              | Sprinkler | 13,965                                    | 12,721                 | 9        |
| Summer  | Pearl millet        | Drip      | 8368                                      | 5031                   | 40       |
|         | Millet              | Drip      | 11,339                                    | 8776                   | 23       |

<sup>a</sup>Data on water saving for castor were taken from [INCID \(1994\)](#).

Source: Kumar, M.D., Singh, O.P., Bassi, N., Niranjana, V., Sharma, M.K., 2010. Hydrological and Farming System Impacts of Agricultural Water Management Interventions for Sustainable Groundwater Use in North Gujarat & Strategies for Improving the Poor Farmers' Access to Groundwater, Final Report submitted to SRTT, Mumbai, Institute for Resource Analysis and Policy, Hyderabad.

**Table A4.2** Estimated irrigation water requirement of selected (irrigated) Kharif crops.

| Crop         | Ajmer | Barmer | Jalore | Jodhpur | Nagaur | Pali  | Sirohi |
|--------------|-------|--------|--------|---------|--------|-------|--------|
| Pearl millet | 150.0 | 338.2  | 338.2  | 351.4   | 241.9  | 240.0 | 350.6  |
| Groundnut    | 233.8 | 532.8  | 532.8  | 482.7   | 358.2  |       | 482.7  |

*Source:* Based on estimation of irrigation water requirement of selected crops grown during the Kharif season from estimated values of PET and effective rainfall.

irrigation water use in crops grown entirely during the rainy season in the region. Making the fairly realistic assumption that by the application of mulch the irrigation needs for the crops grown entirely during rainy season in a normal year can be brought down to zero, the extent of irrigation water use for rainy season crops during a normal year can be considered as the total amount of rainwater that can be saved through mulching (Table A4.2).

From Table A4.2, it is evident that the irrigation water requirement of these two crops is every high and, in a few districts, higher than the rainfall of the district in question. This can happen only if the duration of the crop is long, with the result that the crop stands in the field much beyond the last rains but are reported as irrigated kharif crops. Under such circumstances, crops will not able to harness all the moisture in the soil profile, which is directly available from rainfall and the full crop water requirement will have to be met through irrigation. Therefore, only those crops should be considered wherein the estimated irrigation requirements are the lowest—or crops that are also grown extensively under rain-fed conditions.<sup>m</sup>

Here, the irrigation water requirement in pearl millet (grown extensively under rain-fed conditions in the basin) can be considered for all districts and for all crop areas that receive irrigation during the rainy season. However, this figure can only be applied to only one irrigated crop grown during the rainy season, i.e., groundnut.

$$\text{SAVING}_{\text{RAIN-WATER}} = 0.15 \times \sum_{i=1}^m A_i$$

where  $A_i$  is the area under the rainy season crop  $i$ .

The coefficient will, however, have to change as the rainfall conditions (in terms of duration of rainy season and the quantum of rainfall) change. For other situations, the equation for estimating green water saving can be derived as follows:

$$\text{SAVING}_{\text{RAIN-WATER}} = \Delta_{\text{IRRIGATION}} - \{T - P_{\text{EFF}}\}.$$

<sup>m</sup> Crops that can utilize the maximum amount of rainwater during growth stage.

where  $T$  is the crop transpiration and  $P_{\text{EFF}}$  is the effective rainfall during the crop growing period.

For crops that are purely rain-fed, it is assumed that a total of 50 mm of water could be saved through mulching. This value is quite reasonable. For instance, a study in northwest China on the effect of plastic mulching on crop water use, yield, and soil evaporation for spring wheat (unirrigated) showed that soil evaporation reduced by 0.49 mm per day, while the crop consumptive use (transpiration) increased (by 49 mm) resulting in 82% higher yield and 51% higher water use efficiency (Xie et al., 2005). In water balance models, this can appear as increase in water supplies (green water) during normal years and reduction in pumping for the irrigated rainy season crops.

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