Modeling impact of Agricultural Water Management Interventions on Watershed Hydrology and various Ecosystem Services

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International Crops Research Institute for the Semi-Arid Tropics

Presentation outlines

- Present and future water availability
- Challenges and opportunities
- Need for Agricultural water management interventions

Showing case-studies

- Kothapally watershed, Andhra Pradesh, Southern India
  - Modeling brief
  - AWM Impacts
- Garhkundar watershed, Bundelkhand region, Central India
  - AWM Impacts

- Up-scaling scenario: Osman Sagar catchment
- Conclusions

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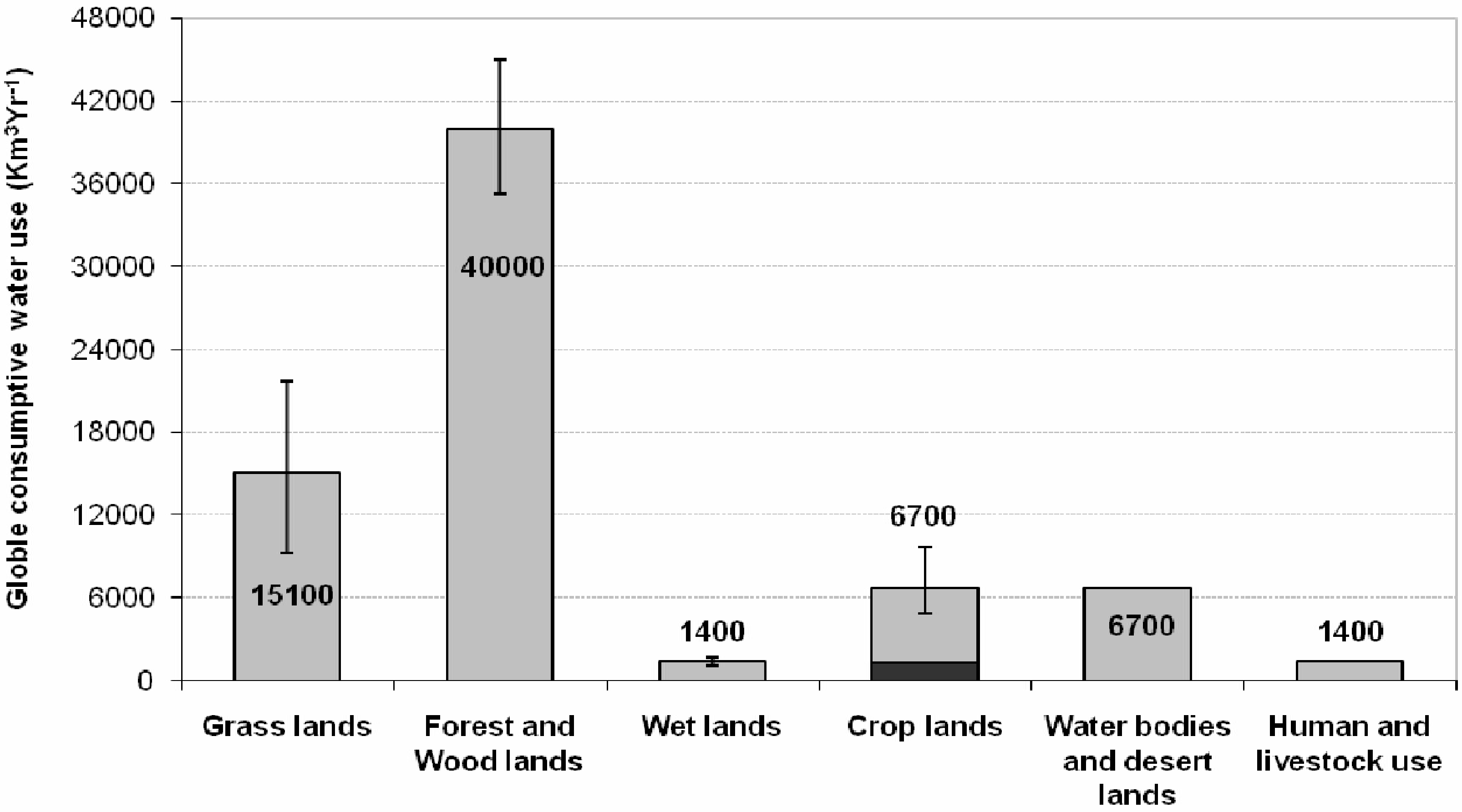
Global water balance



Annual precipitation on Earth surface = 110,305 Km^3 (90,000-120,000 Km^3)
Total runoff returning back to Ocean = 38,230 Km^3 (34.7 %)
Expected ET from Earth surface = 72,075 Km^3 (65.3 %)
Total ET reported (in current figure) = 71,300 Km^3

Source: Rockstrom *et al*., 1999

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Type of water resources

- Blue water resource: Water available in rivers, groundwater aquifers and reservoirs

- Green water resource: Water stored as soil moisture

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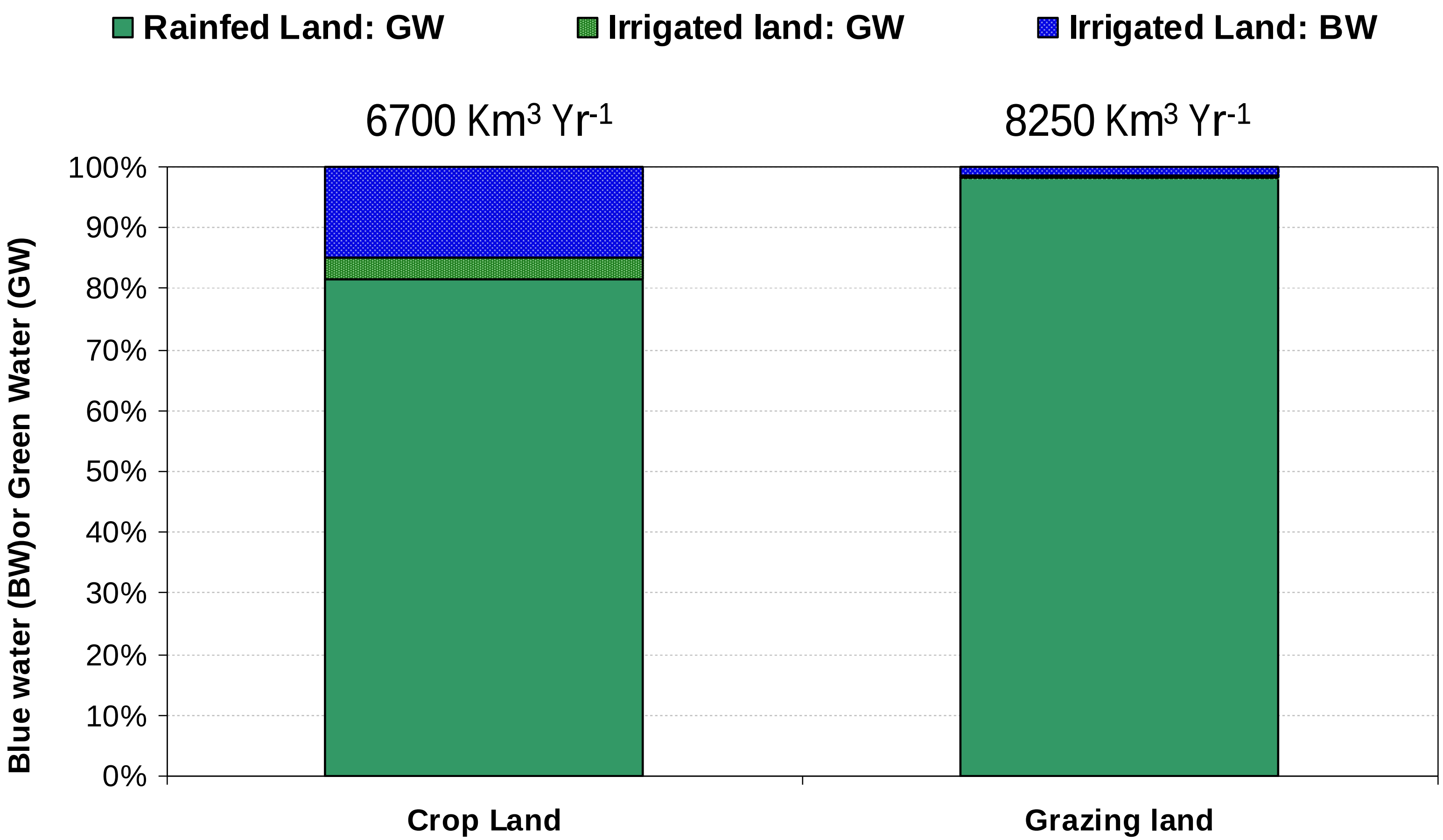
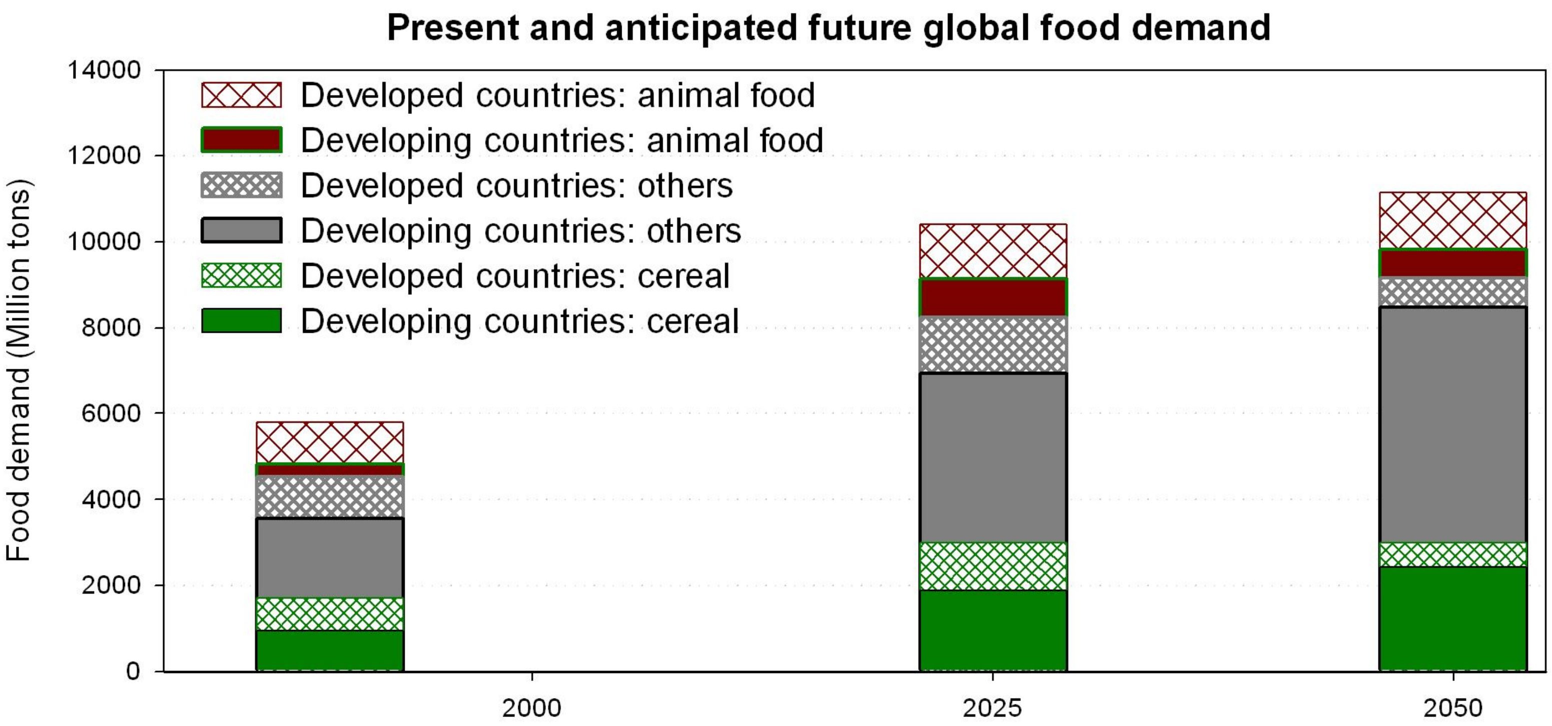
Green water is dominating in global food production compared to blue water

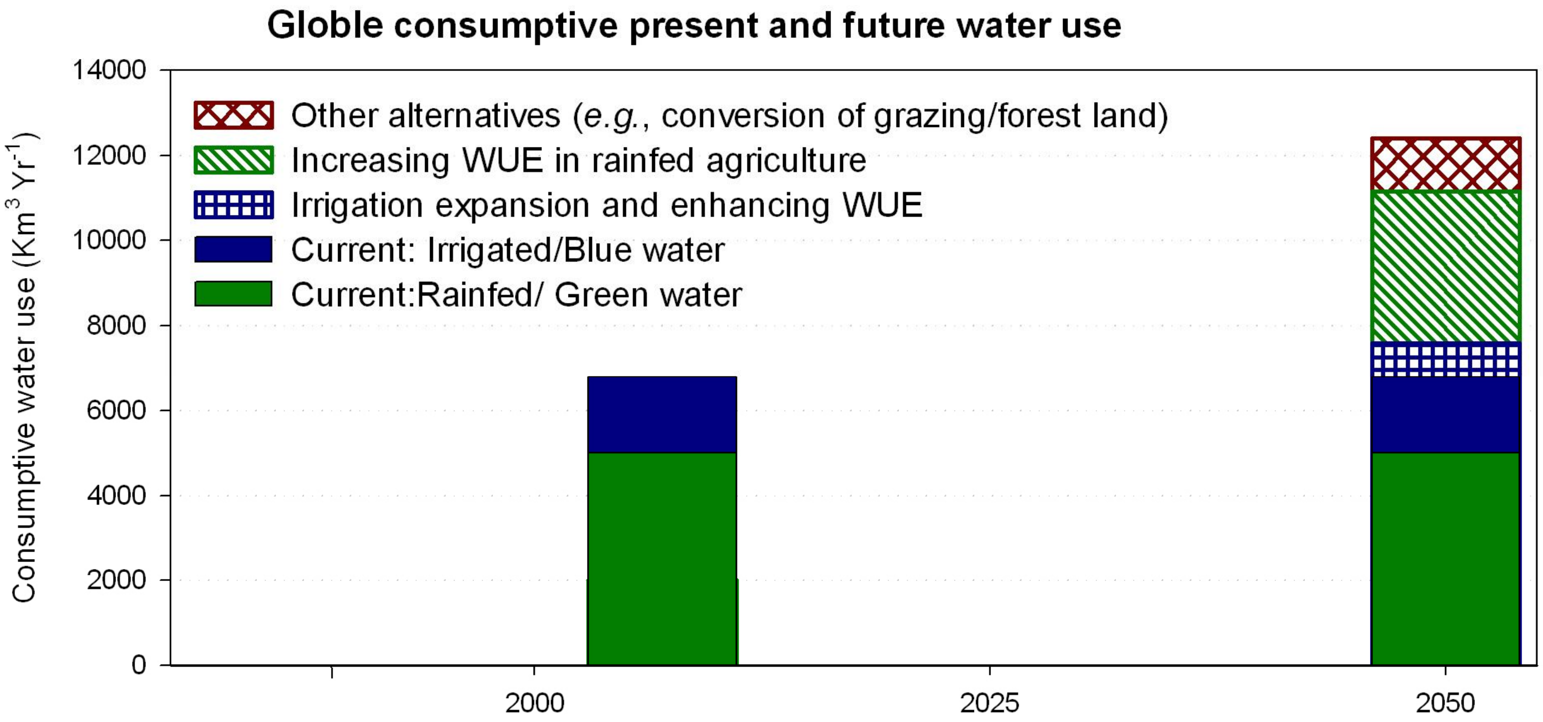


Source: Rost *et al*., 2008; Rockstrom *et al*., 1999

Food demand in 2050 will be doubled than the current requirements



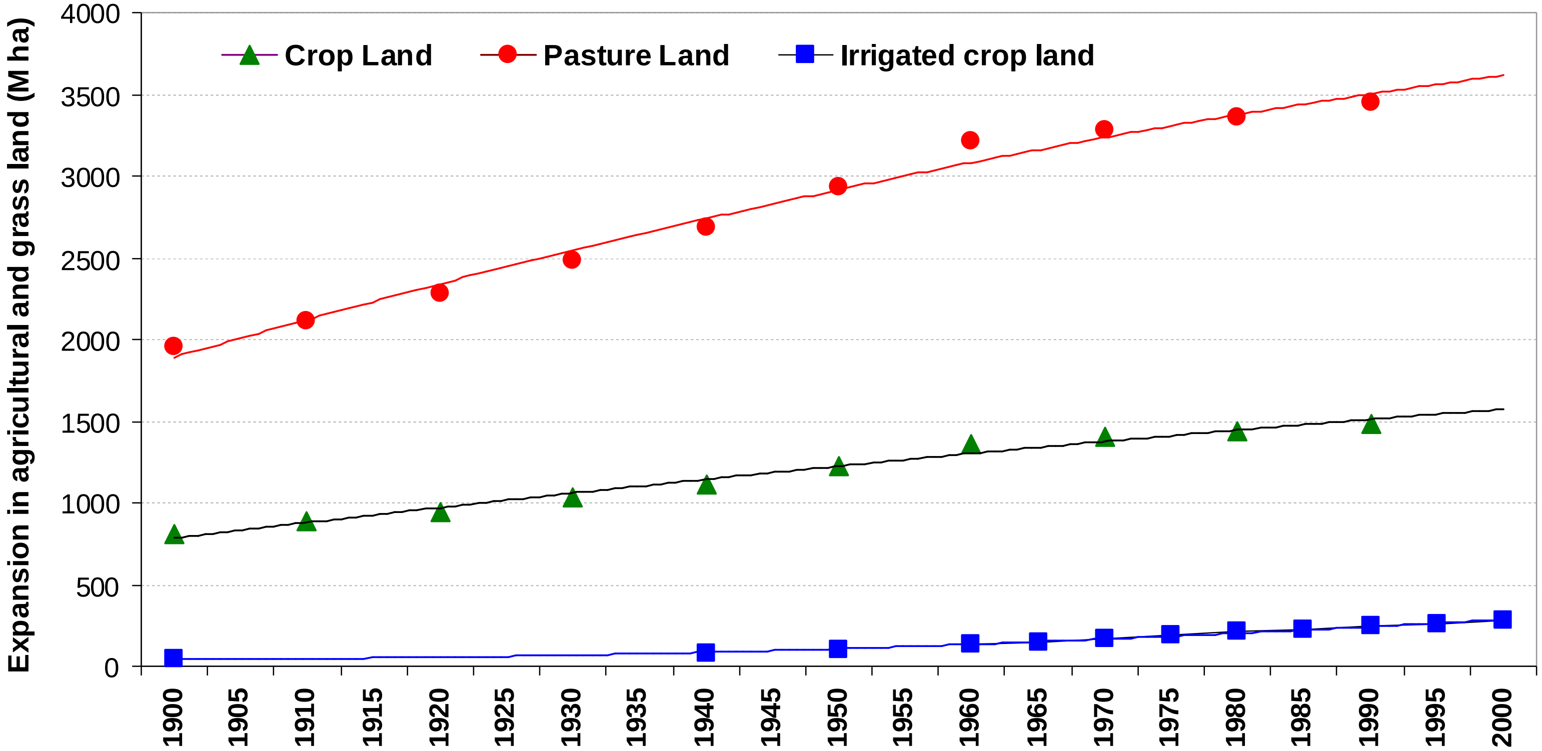
Fresh water requirement in 2050 also will be doubled but...



From where the additional fresh water will come or any alternate source/solutions?

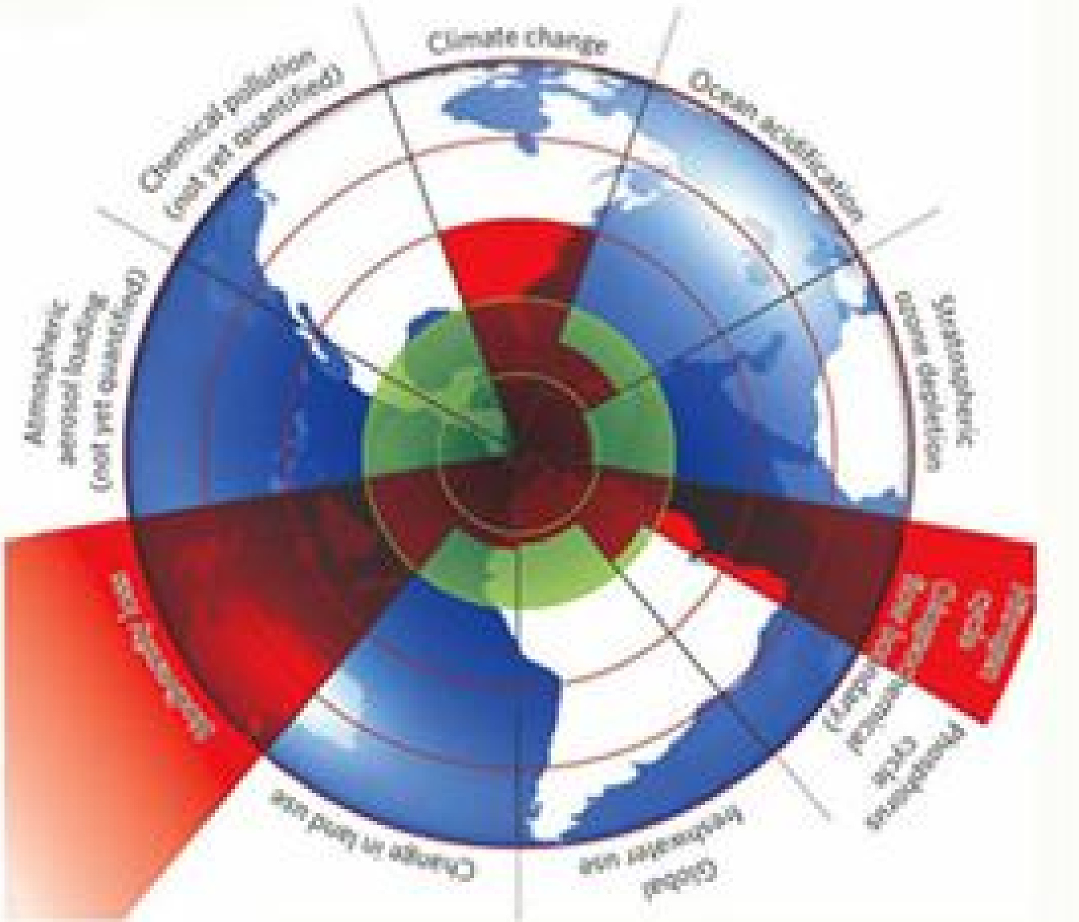
Option-1: Expanding the agricultural land !

Crop and pasture lands have already crossed its thresholds limits



Planetary Boundaries: Safe Operating Space for Humanity

1. Climate change
2. Ocean acidification
3. Ozone depletion
4. N cycle
5. P Cycle
6. Fresh water use
7. Land use
8. Biodiversity loss
9. Aerosol loading
10. Chemical pollution



Biodiversity loss, Nitrogen cycle and climate change are various parameters has reached beyond its permissible threshold at planetary scale

Nature, 2009

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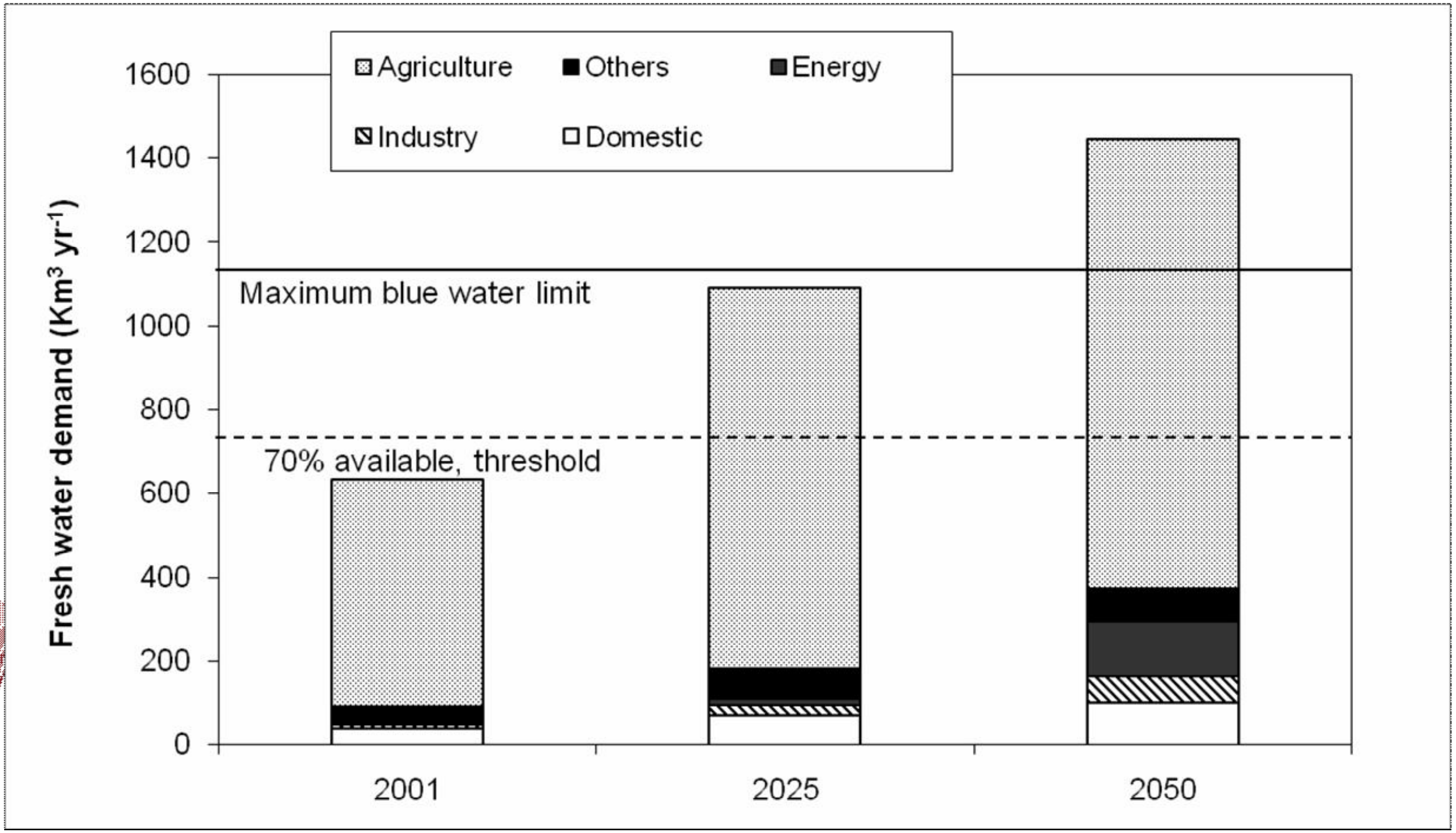
Option-2: Opportunities to expand water resources availability in crop lands !

Example India case



Source: CWC, Government of India

Groundwater use status in India

Details	Values
Total Agricultural Land	142 Million ha
Rainfed area	~ 60%
Irrigated area	~ 40%
Surface water irrigated area	21 Million ha
Groundwater irrigated area	27 Million ha
Total groundwater withdrawal (1960)	25 Km^3
Total groundwater withdrawal (2009)	250-300 Km^3
Number of bore wells (1960)	1 Million
Number of bore wells (2009)	20 Million

Garg and Wani, 2012

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Option-3: Sustainable Intensification, Watershed-based Land Use Planning, Increased Efficiency of Resources

- Land
- **Water**
- Energy
- Nutrients
- Labor
- Chemicals

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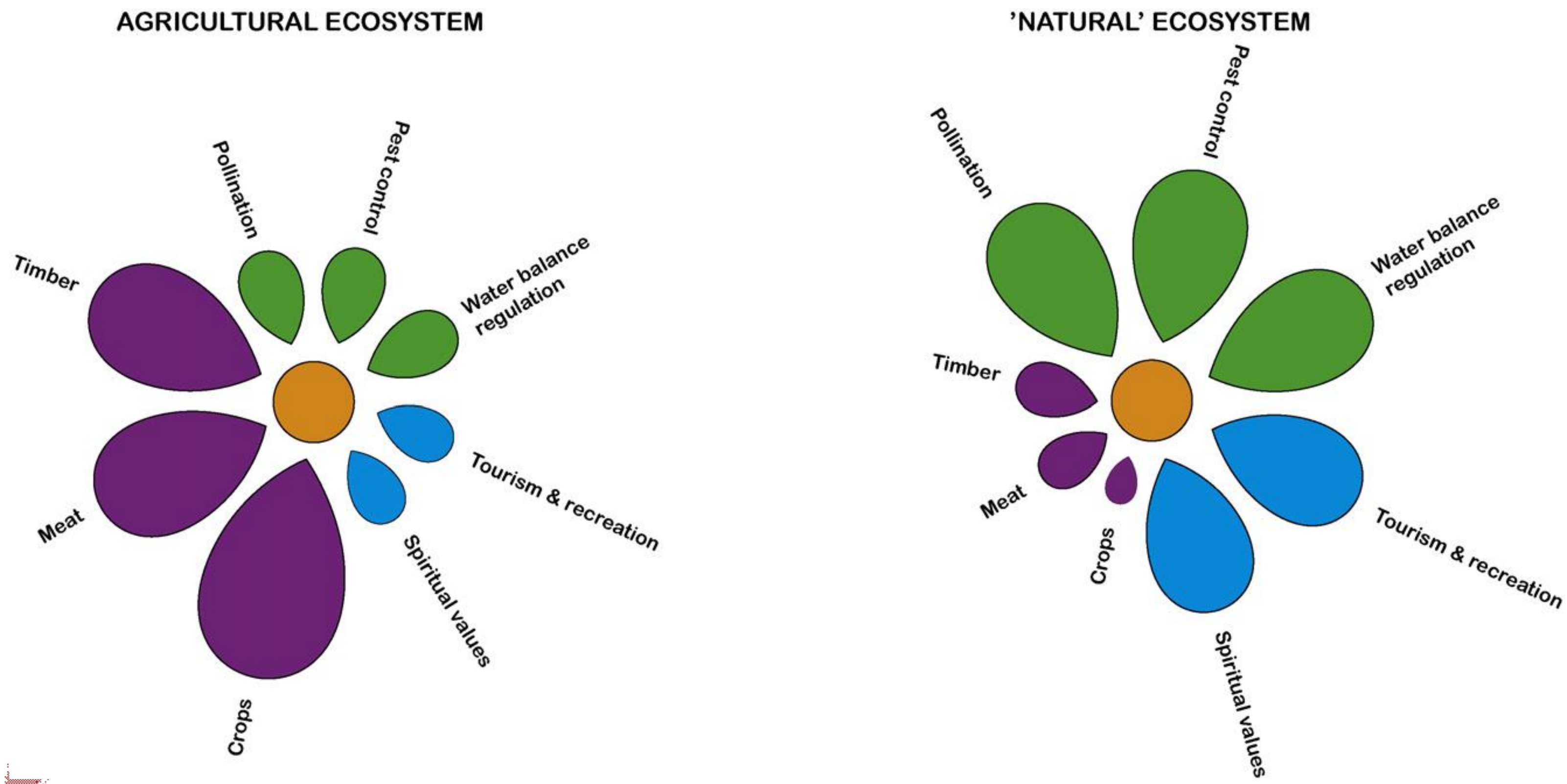
Agriculture generally increases provisioning ecosystem services at the expense of regulating and cultural ecosystem services



Ecosystem Services

Provisioning : Crop, Timber, Meat, Mineral, Fish

Regulating : Soil formation, Pollination

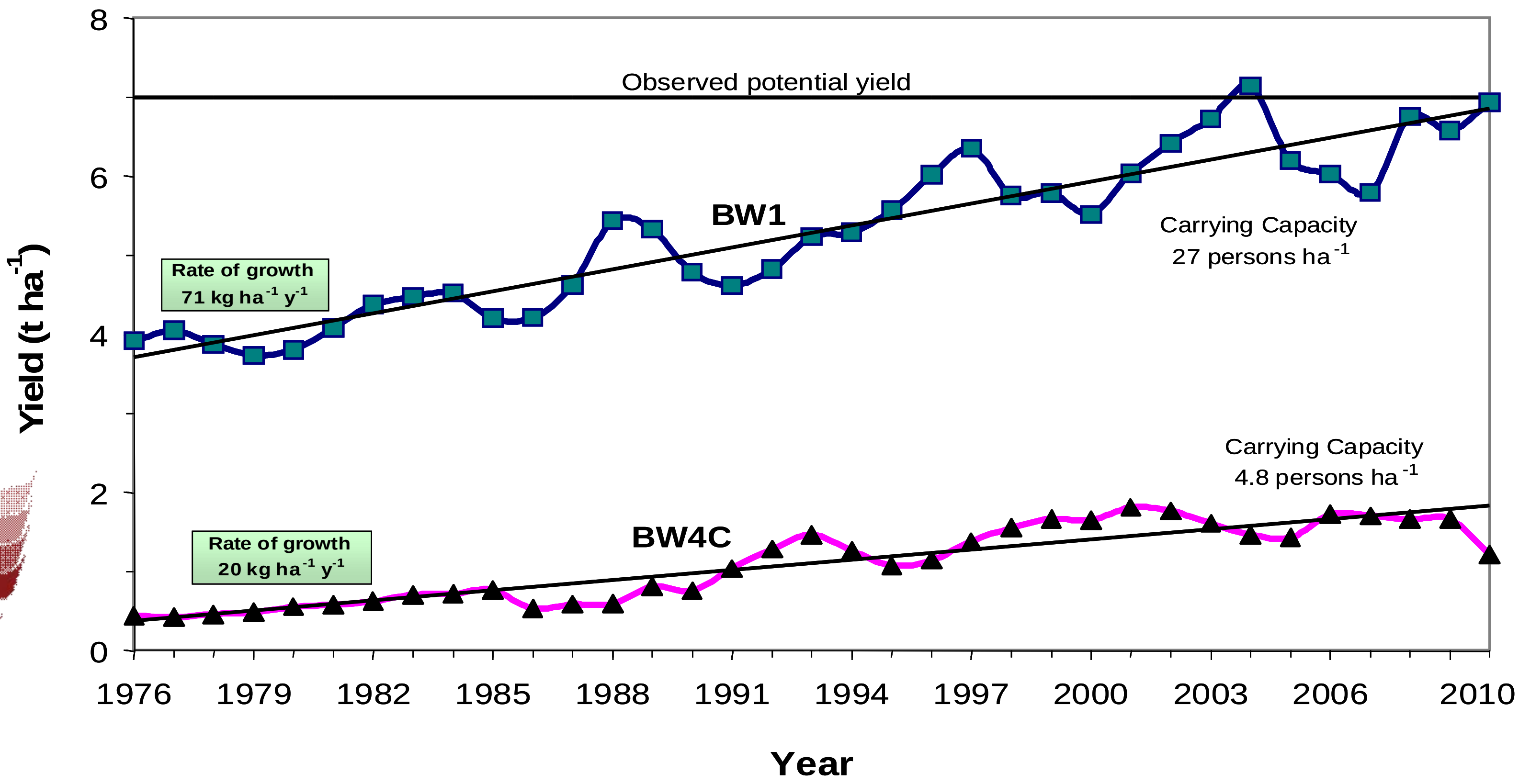
Supporting: Erosion control, GW recharge

Cultural: Tourism, Aesthetic

Gordon et al., 2009

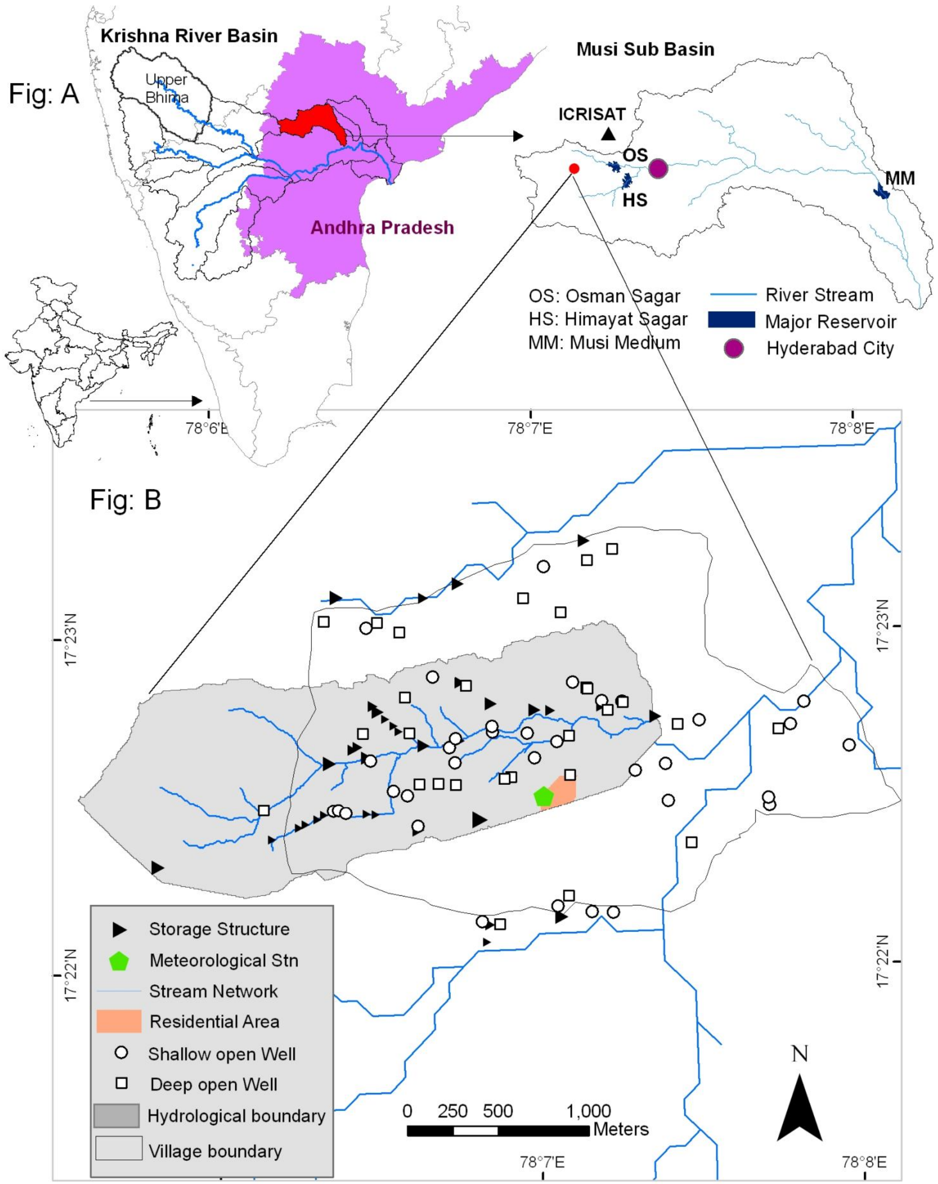
Rainfed agriculture: a large untapped potential

- Current farmers' yields are lower by 2 to 5 folds than the achievable yields
- Vast potential of rainfed agriculture needs to be harnessed



Wani et al., 2012

ICRISAT led consortium developed AWM interventions in Kothapally watershed from 1999 onwards



Agricultural Water Management Interventions

***In-situ* intervention**

- Land form treatment (BBF)
- Contour cultivation
- Bunds and field bunding
- Mulching and no-tillage

***Ex-situ* Interventions**

- Check dam, farm ponds
- Mini percolation pits
- Gully control structures
- Loose boulders

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Field-based soil and water conservation measures (*in-situ* practices) enhances green water availability

- Contour cultivation
- Broad Bed and Furrow
- Cultivation across the slope
- Border strips
- Field bunds
- Conservation agriculture /min tillage
- Mulching

Conservation furrow system, Mahaboobnagar, A.P.

chickpea on BBF-Furrow, ICRISAT farm

Groundnut on BBF, Kurnool, A.P.

Ex-situ interventions help in recharging groundwater

How much ???

Water harvesting structure in Garhkundar watershed, Jhansi

Low-cost mini percolation tank

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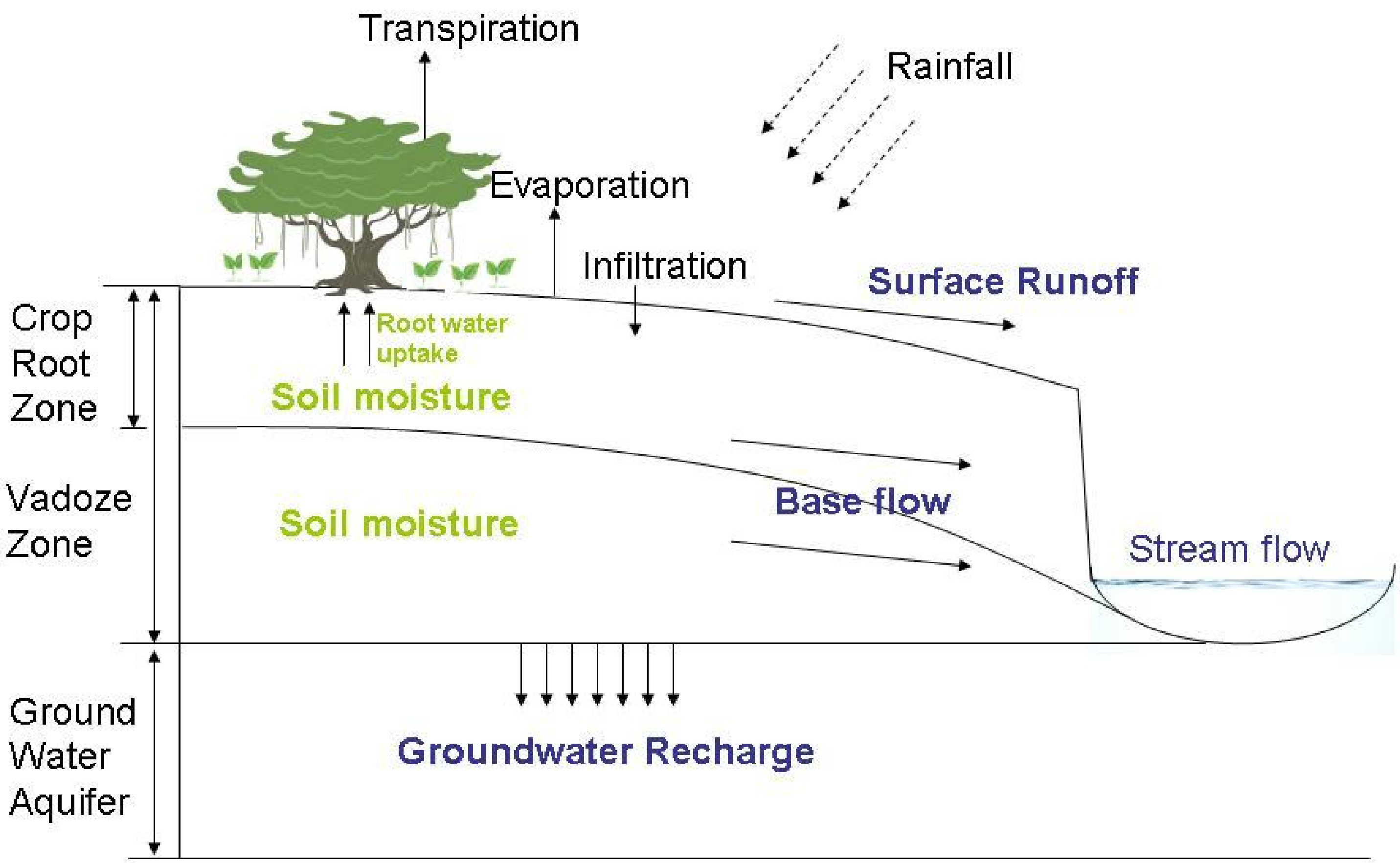
Hydrological components at watershed scale



Rainfall = Surface Runoff + Groundwater recharge + ET + Change in soil moisture storage

Hydrological model SWAT is applied for analyzing impact of AWM interventions

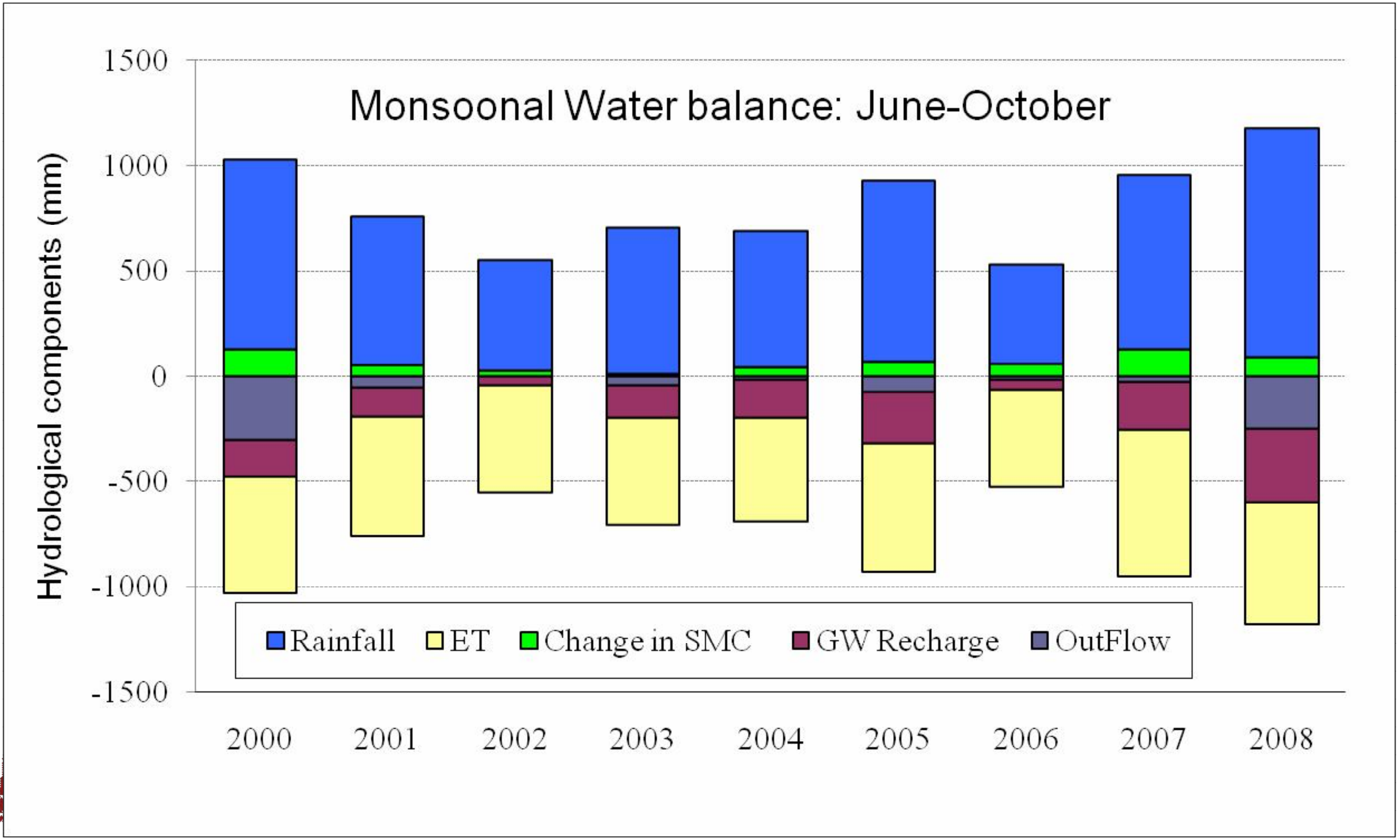
SWAT Input:
- Digital Elevation model
- Soil Information
- Land use Information
- Meteorological Information
- Management Information
- Reservoir/Pond Information

→ **Model Calibration and Validation** →

SWAT Output:
- Surface runoff
- Groundwater recharge
- Evapotranspiration
- Sediment Transport
- Nutrient Transport
- Soil moisture
- Water, N and P stress
- Crop Growth and yield

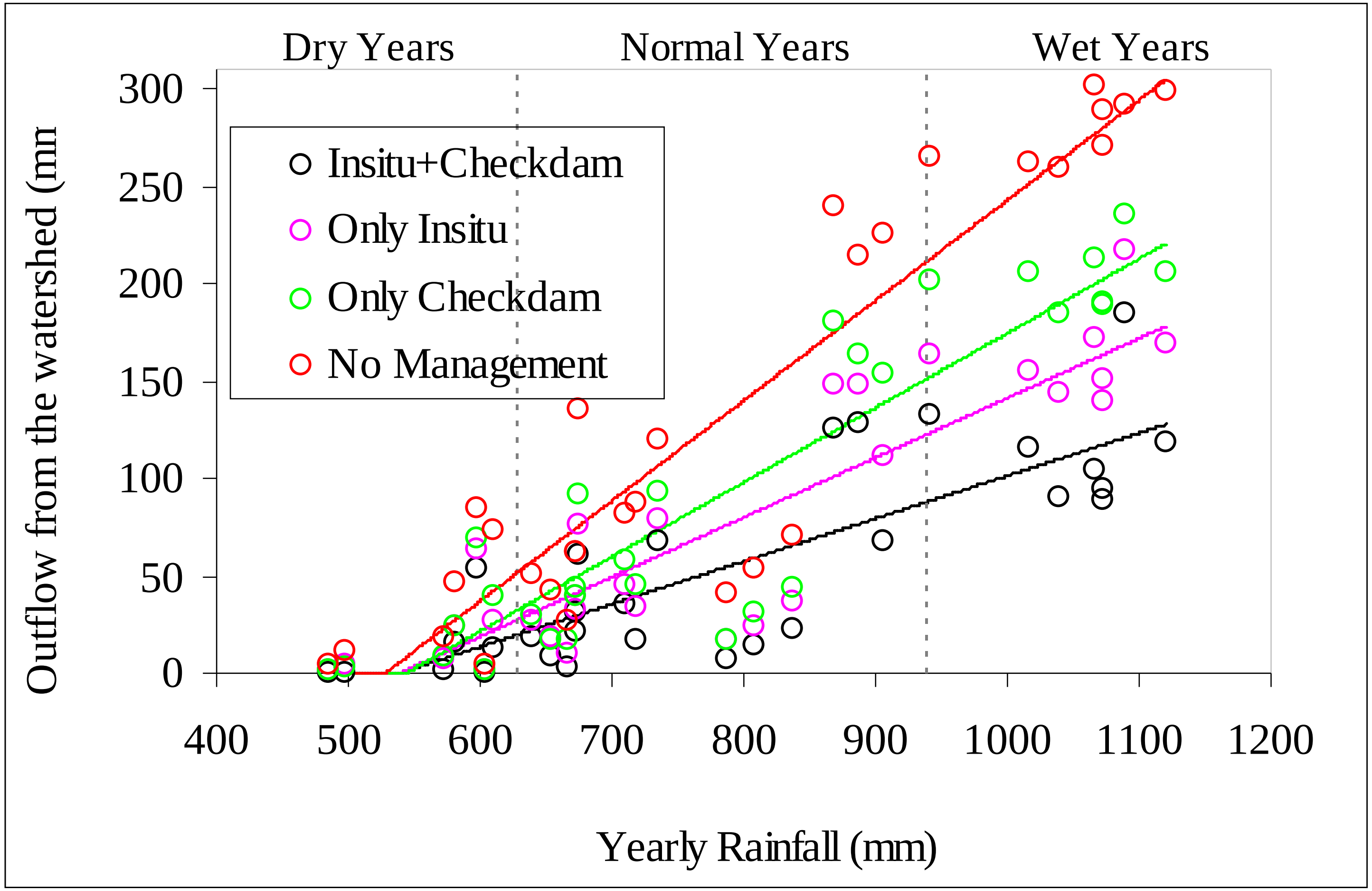
Water balance components:
Rainfall = Surface Runoff + Groundwater recharge ET + Change in soil moisture storage

Monsoonal Water Balance at Kothapally: Jun to Oct



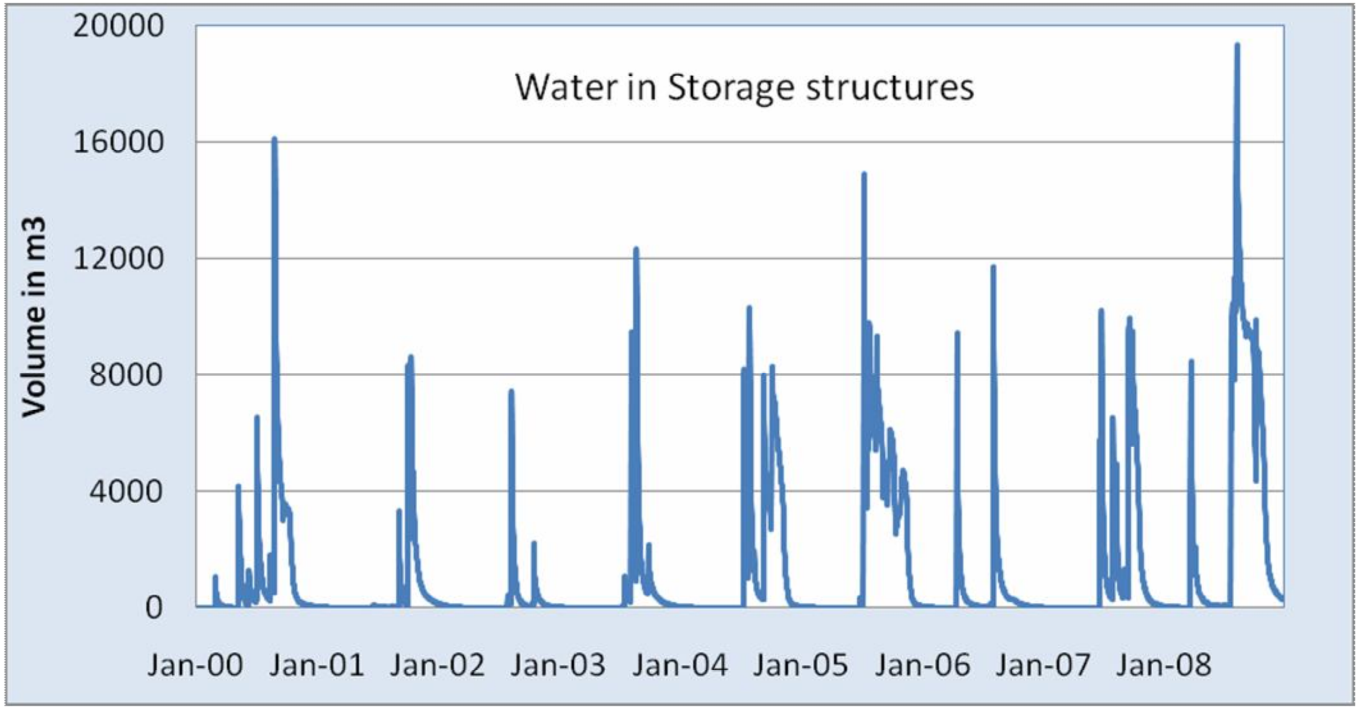
Rainfall (mm)	Outflow (mm)	GW Recharge	ET (mm)	Other (mm)
750	60 (8 %)	120 (16 %)	540 (72 %)	30 (4 %)

AWM interventions reduced surface runoff by 30-60 %



Garg et al., 2012

Check dam harvested water three to four times than their storage capacity



Year	Total Amount of water Captured (m3)	Potential Storage capacity	Ratio to Potential storage
2000	30242	8880	3.4
2001	18787	9980	1.9
2002	9768	11230	0.9
2003	23369	13030	1.8
2004	33494	13030	2.6

Year	Total Amount of water Captured (m3)	Potential Storage capacity	Ratio to Potential storage
2005	35955	13030	2.8
2006	20987	13030	1.6
2007	41866	13030	3.2
2008	42531	13030	3.3

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Water harvesting potential is higher in *in-situ* practices than *ex-situ* interventions

Year	Average Annual Rainfall (mm)	Capacity of the check dams to store water (m^3/ha)	Total water harvested by Check dams in one year period (m^3/ha)	Total water harvested by Insitu practices in one year period (m^3/ha)	Un-Harvested amount (m^3/ha)
Dry	650	45	55	100	125
Normal	870	45	105	350	425
Wet	1210	45	175	650	1475

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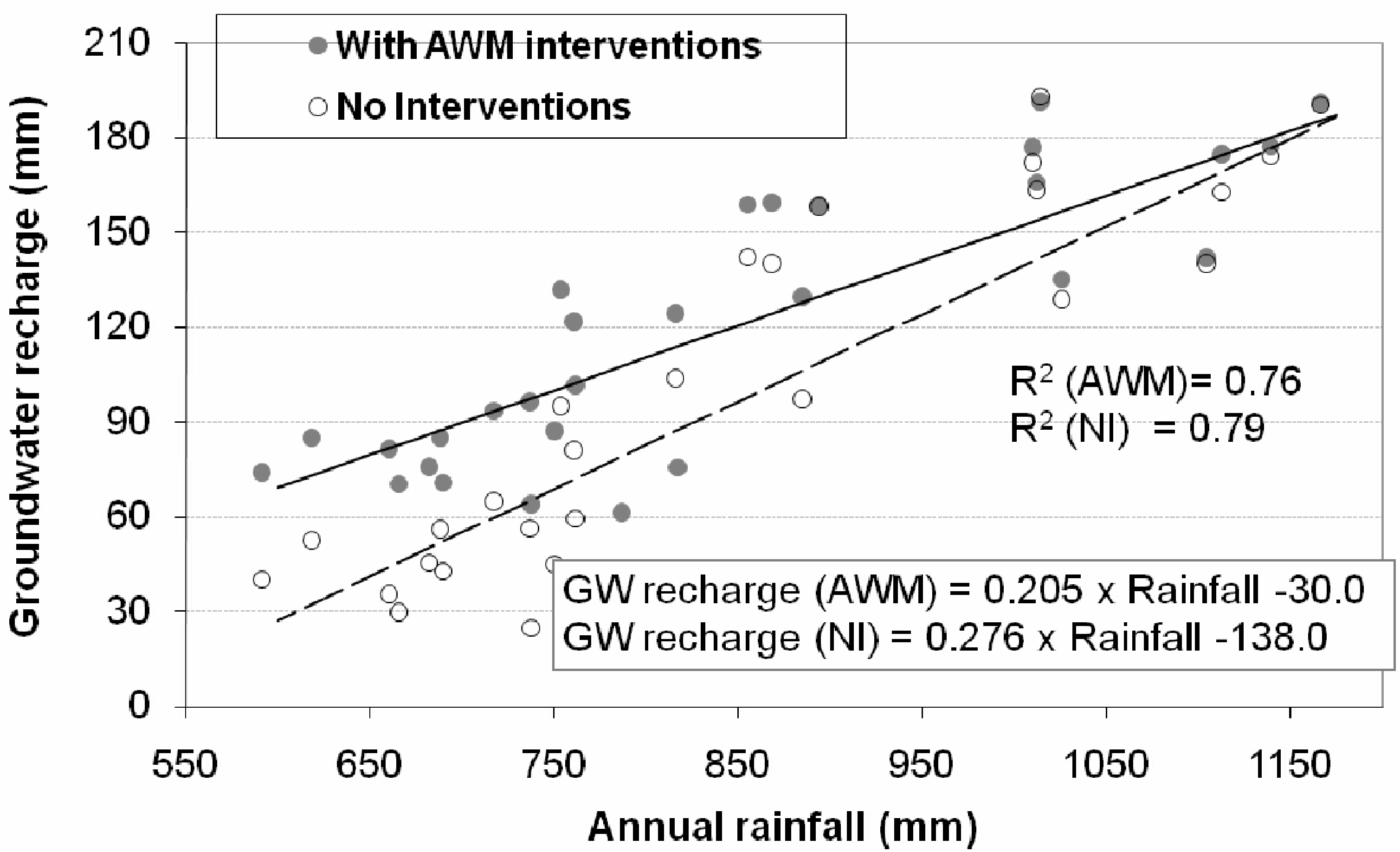
AWM interventions enhanced groundwater recharge by 50-80 %



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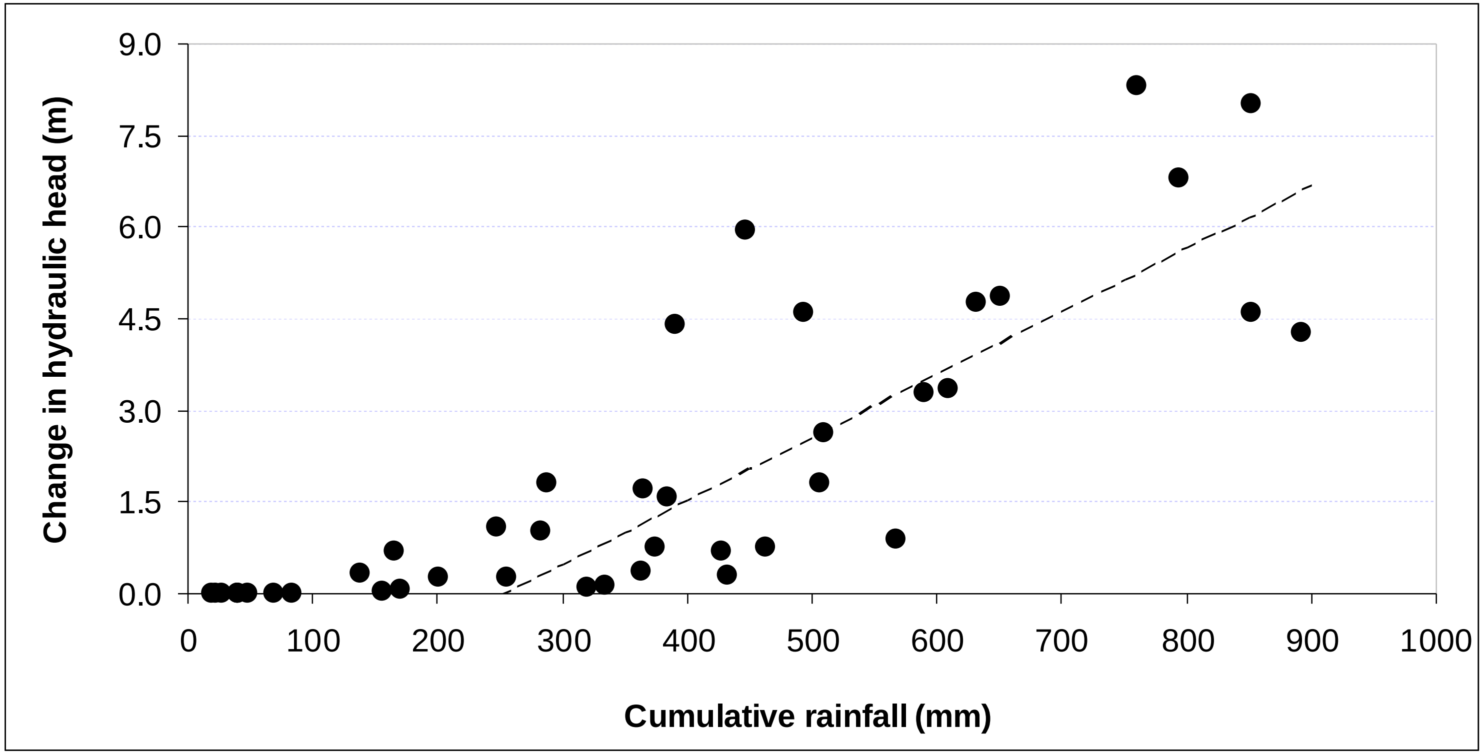
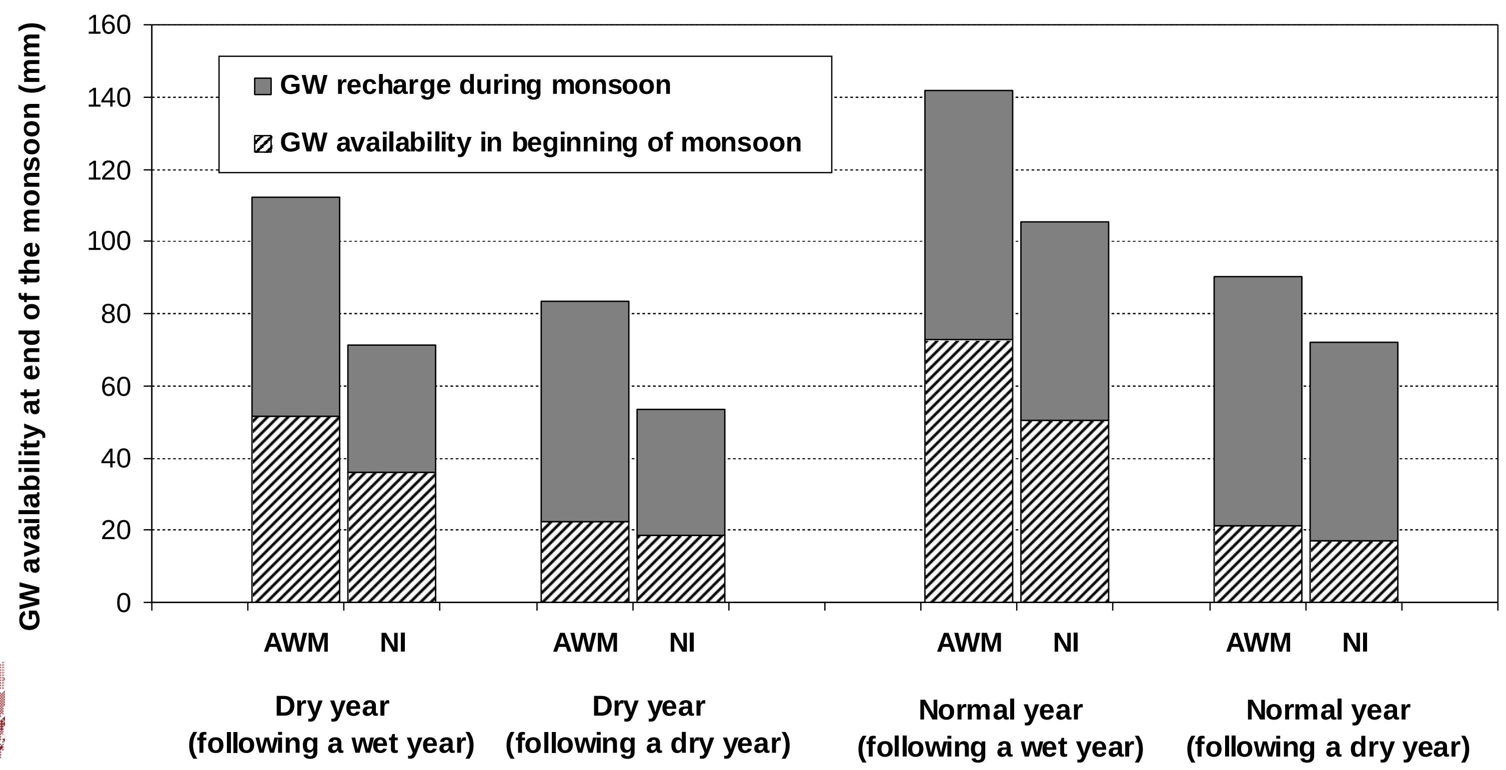
GW recharge starts with nearly 250 mm cumulative rainfall in SAT



Groundwater availability in a given year also dependent on previous GW stages



Water balance in Kothapally watershed
No Int. vs. Max Int.

Hydrological Parameters	No Intervention stage	After AWM interventions
Rainfall (mm)	750	750
Runoff (mm)	143 (19 %)	60 (8 %)
ET (mm)	512 (68 %)	540 (72 %)
GW recharge (mm)	70 (9 %)	120 (16 %)
Change in SMC (mm)	25 (3 %)	30 (4 %)

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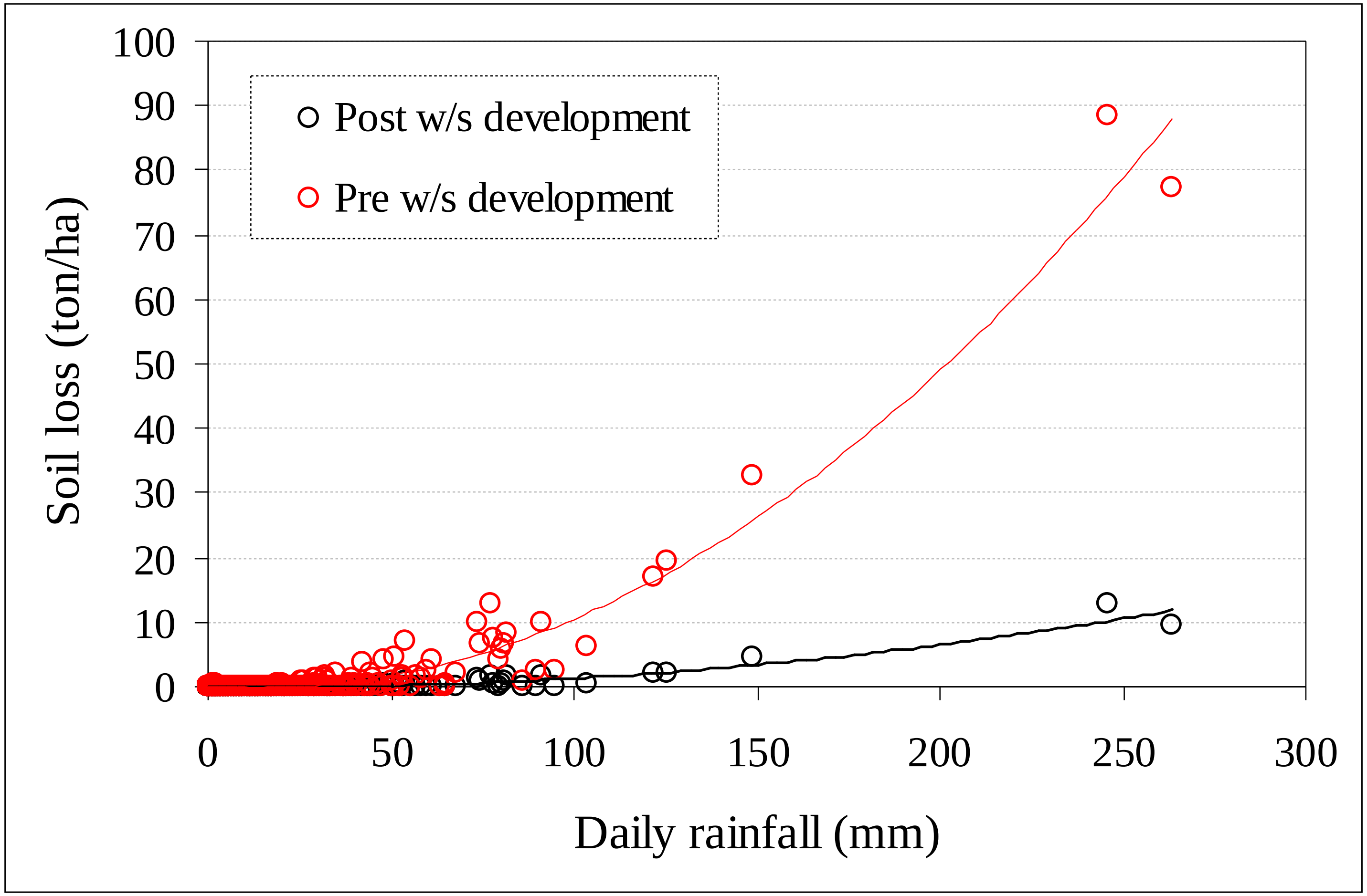
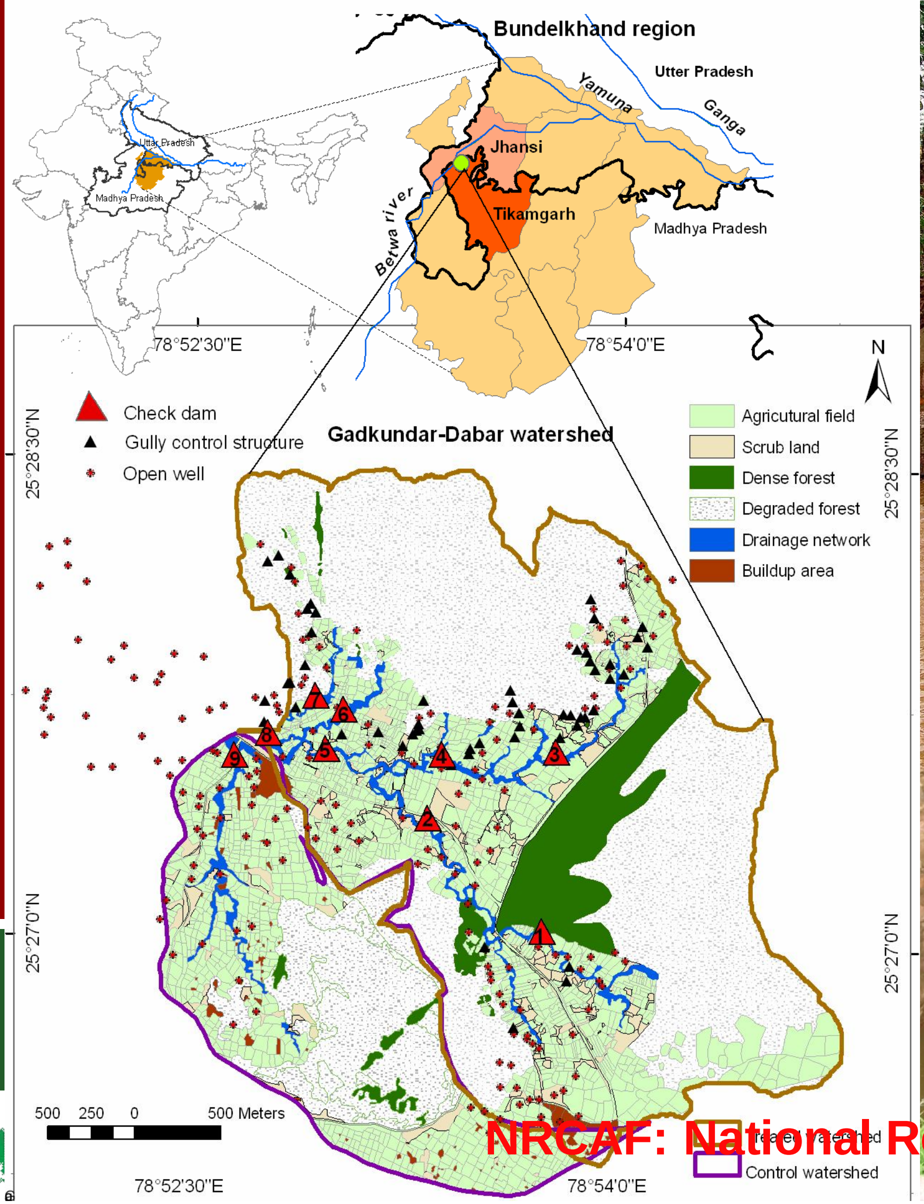
Soil loss reduced by 3 to 5 folds after implementing AWM interventions

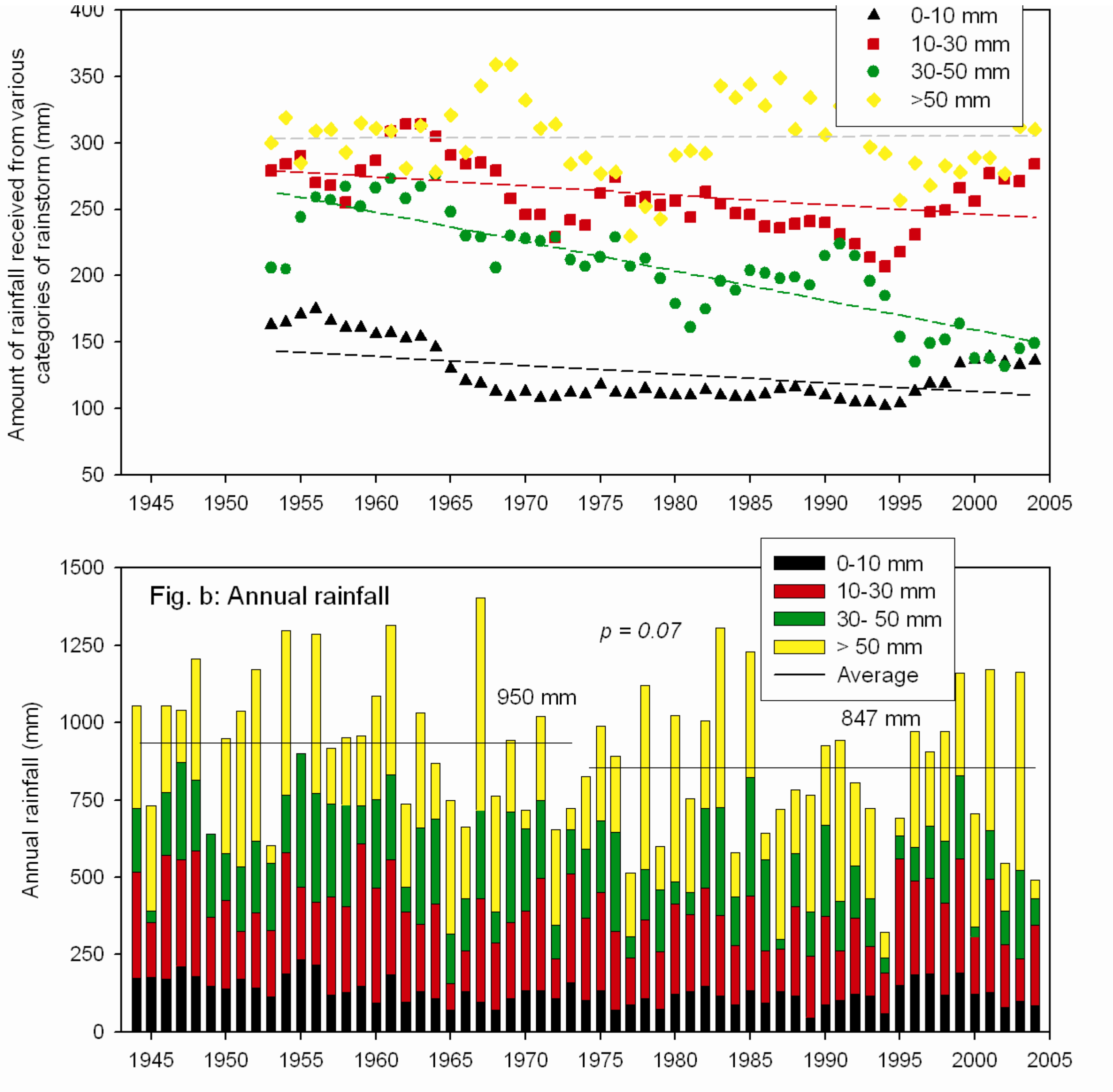


Impact of water management interventions in Garhkundar-Dabar watershed, Bundelkhand region, Central India

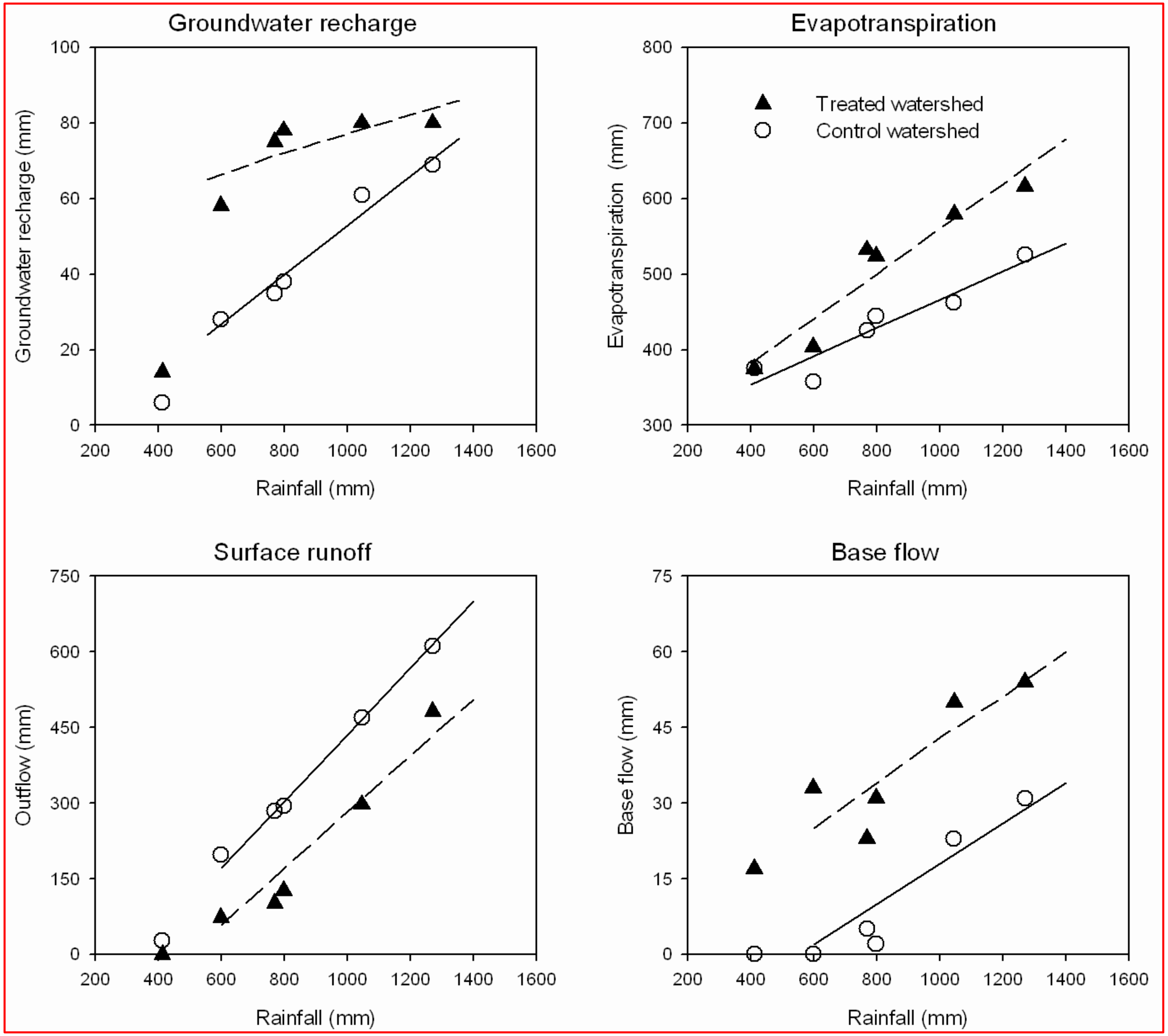


NRCAF: National Research Centre for Agro-Forestry, Jhansi

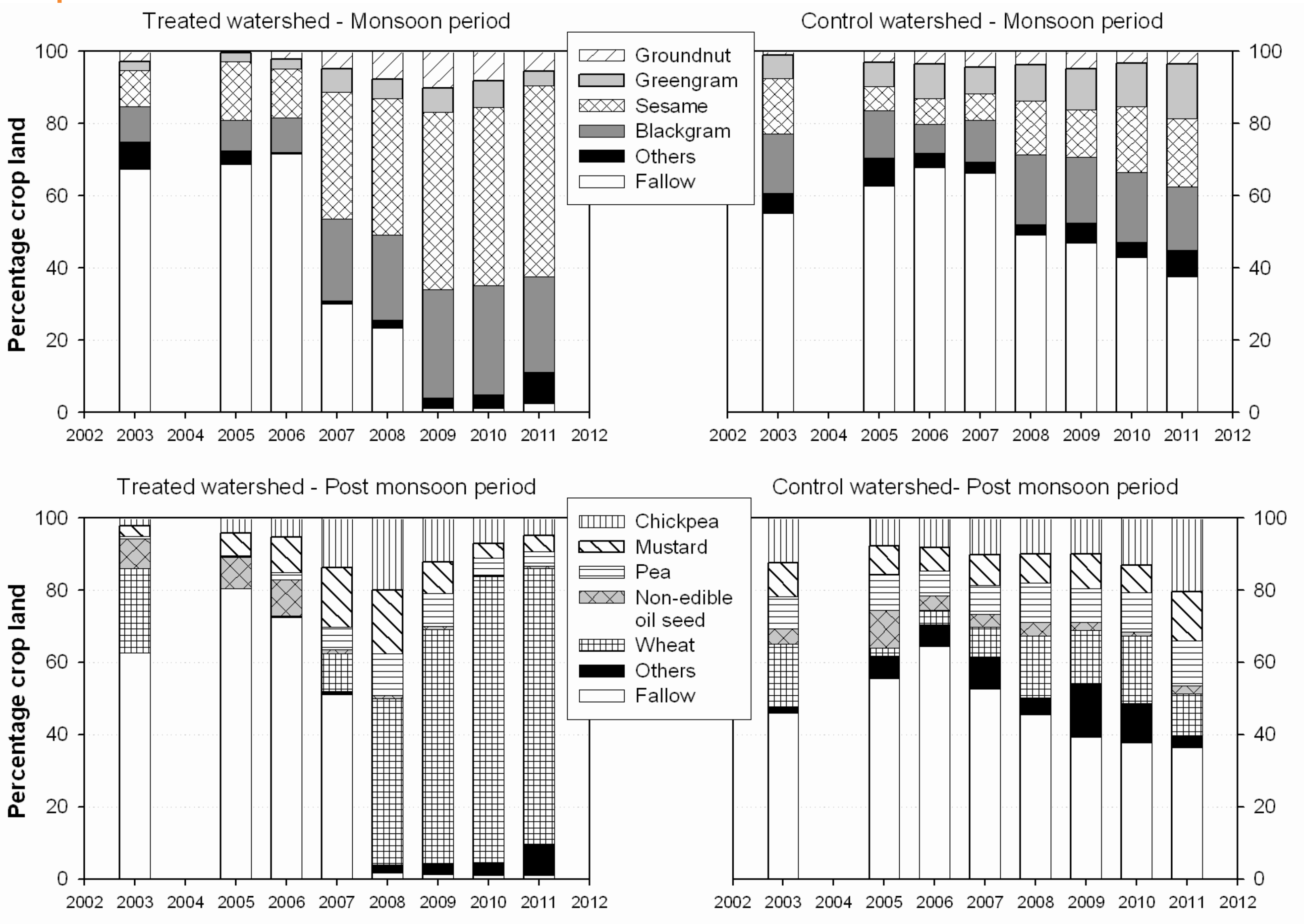
Changing rainfall pattern in Jhansi, Bundelkhand, Central India



Hydrological components: Treated vs. non-treated

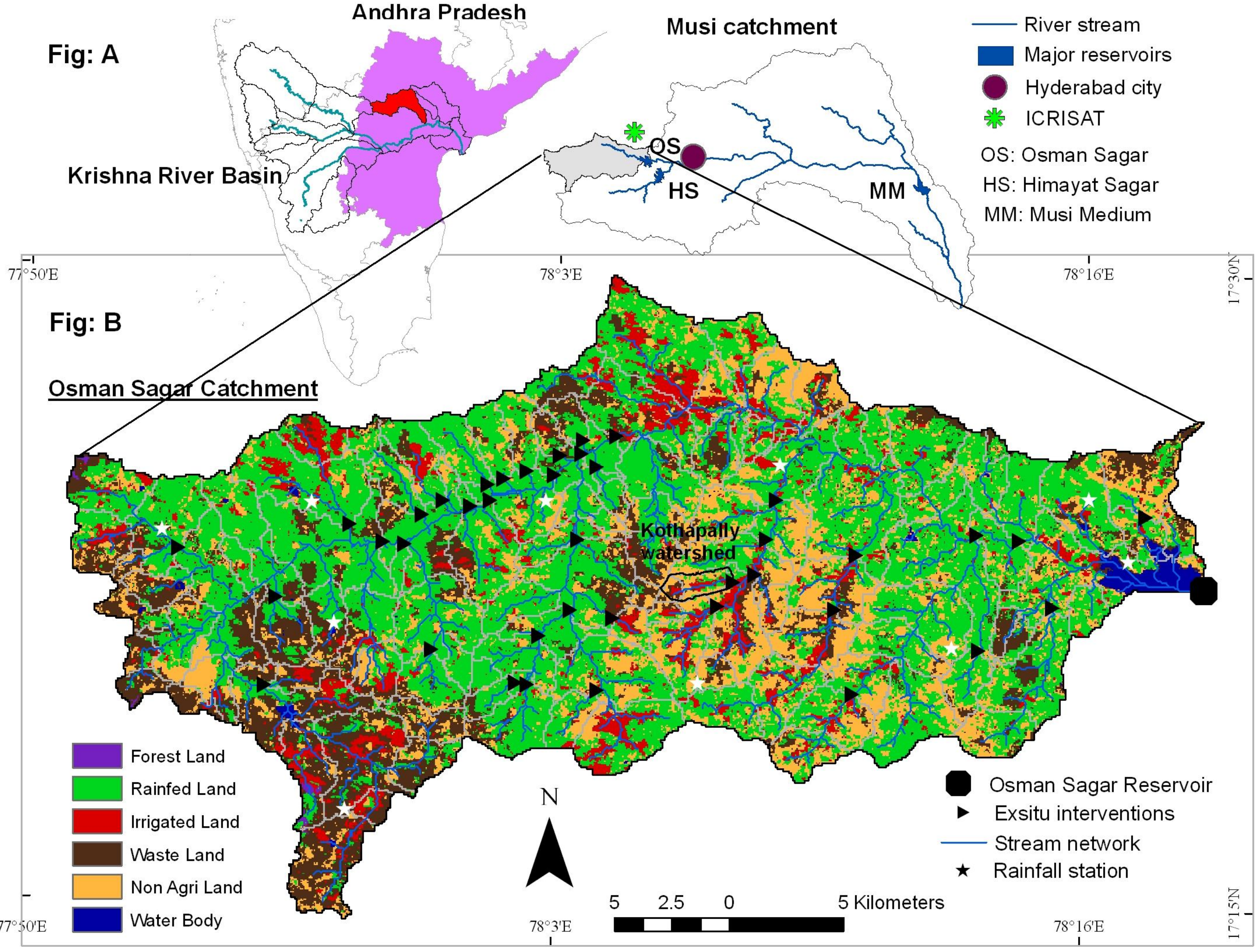


Cropping intensity in GKD watershed doubled



Singh et al., 2013

Up-scaling AWM interventions
Scenario analysis for Osman Sagar catchment



Upstream vs. downstream in Osman Sagar catchment

Upstream land use

Total geographical area (Osman Sagar catchment) = 75000 Ha

- Rainfed area = 42%
- Irrigated area = 8%
- Waste land = 23%
- Non Agriculture use = 23%
- Forest = 4%

Downstream user

Drinking water source for the Hyderabad (~ 8-10 % of domestic water demand of the city)

Source	Inflow to OS reservoir	62 MCM
Uses	Domestic use	30 MCM
	Spillover at downstream	12 MCM
	Evaporation	20 MCM

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Impact of AWM interventions

Water Year	Parameters	Current stage	No Int.	Insitu	Exsitu	Max Int.
Normal years Average annual rainfall: 740 mm	Groundwater recharge (MCM)	96	82	83	104	98
	Potential irrigated area for growing second crop (km^2)	125	100	105	135	128
	Average yield of monsoon crop (ton/ha)	-	1.4	1.7	1.6	1.8
	Inflow to Osman Sagar (MCM)	56	73	70	48	47
	Total crop production in monsoon period (1000 tons)	-	21	27	25	27
	Spillover releases downstream to the Musi river (MCM)	1	11	1	0	0
	Soil Loss (ton/ha)	13	17	16	9	9

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Garg et al., 2012

Conclusions

- Rainfed areas have large untapped potential which could be harnessed thru improved land, water and nutrient management practices
- Watershed management is suitable adaptation and mitigation strategies to address current and future food security issues
- Micro (field) and meso (watershed) scale monitoring need to be intensified in different agro-ecological regions along with modeling effort for effective resource planning

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Further details of methodology and results, please refer…

Kaushal K. Garg, Louise Karlberg, Jennie Barron, Suhas P. Wani and Johan Rockstrom (2012). Assessing impacts of agricultural water interventions in the Kothapally watershed, Southern India. ***Hydrological Processes*** 26: 387-404

Kaushal K. Garg and Suhas P. Wani (2012). Opportunities to Build Groundwater Resilience in the Semi-Arid Tropics. ***Groundwater***, National GroundWater Association. doi: 10.1111/j.1745-6584.2012.01007.x

Kaushal K. Garg, Suhas P. Wani, Jennie Barron, Louise Karlberg and Johan Rockstrom (2012). Up-scaling potential impacts on water flows from agricultural water interventions: opportunities and trade-offs in the Osman Sagar catchment, Musi sub-basin, India. ***Hydrological Processes.*** DOI: 10.1002/hyp.9516

Suhas P Wani, Kaushal K Garg, Anil K Singh and Johan Rockstrom (2012). Sustainable management of scarce water resource in tropical rainfed agriculture. ***Advances in Soil Science***. *In* Soil Water and Agronomic productivity (by Lal and Stewart) Chapter 13, page no 347-408.

Ramesh Singh, Kaushal K Garg, Suhas P Wani, R K Tewari, S K Dhyani (Forthcoming). Impact of water management interventions on hydrology and ecosystem services in Garhkundar-Dabar watershed of Bundelkhand region, Central India. ***Journal of Hydrology* 2013**

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Thank You

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