Assessment of temporal and spatial effects of land use changes on wetland hydrology: A case study from South Africa

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OUTLINE

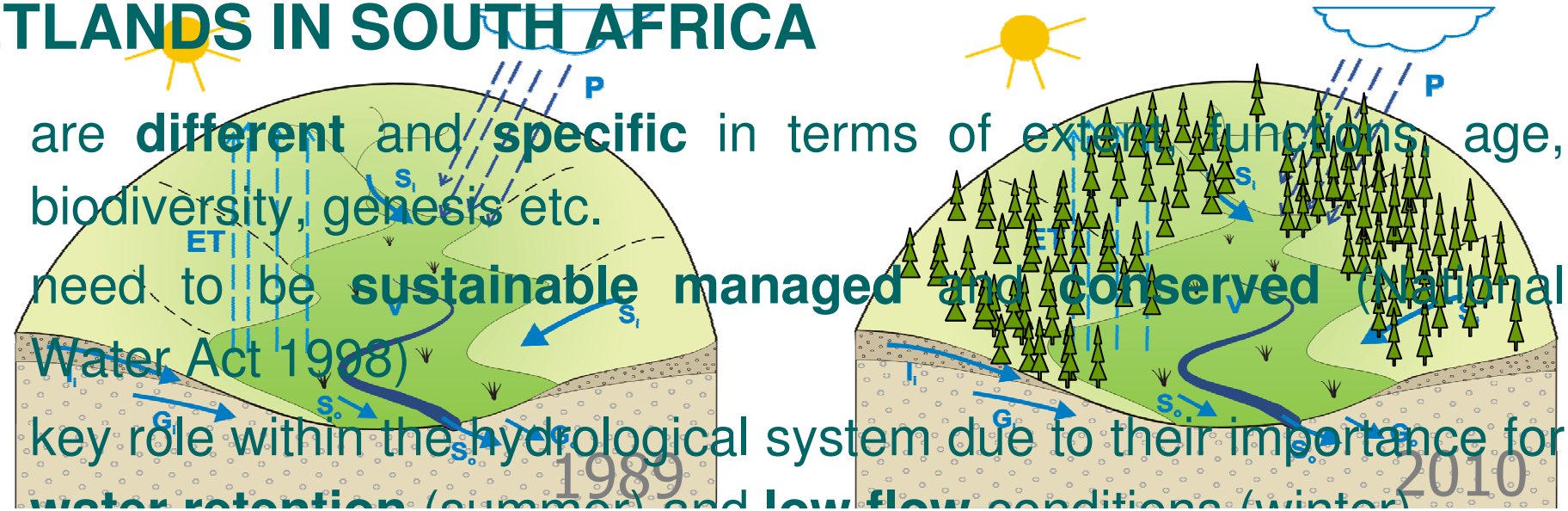
- Introduction
- Study Area
- Base Studies
- Wetland Classification
- Modeling Approach
- Model Results
- Conclusion
- Acknowledgements

BACKGROUND

- Study on landscape dynamics due to the temporal and spatial impact of large scale afforestation on different wetland types within the semi-arid headwaters of the Umzimvubu catchment, South Africa.

WETLANDS IN SOUTH AFRICA

- are **different** and **specific** in terms of extent, functions, age, biodiversity, genesis etc.
- need to be **sustainable managed** and **conserved** (National Water Act 1998)
- key role within the hydrological system due to their importance for **water retention** (summer) and **low flow** conditions (winter)



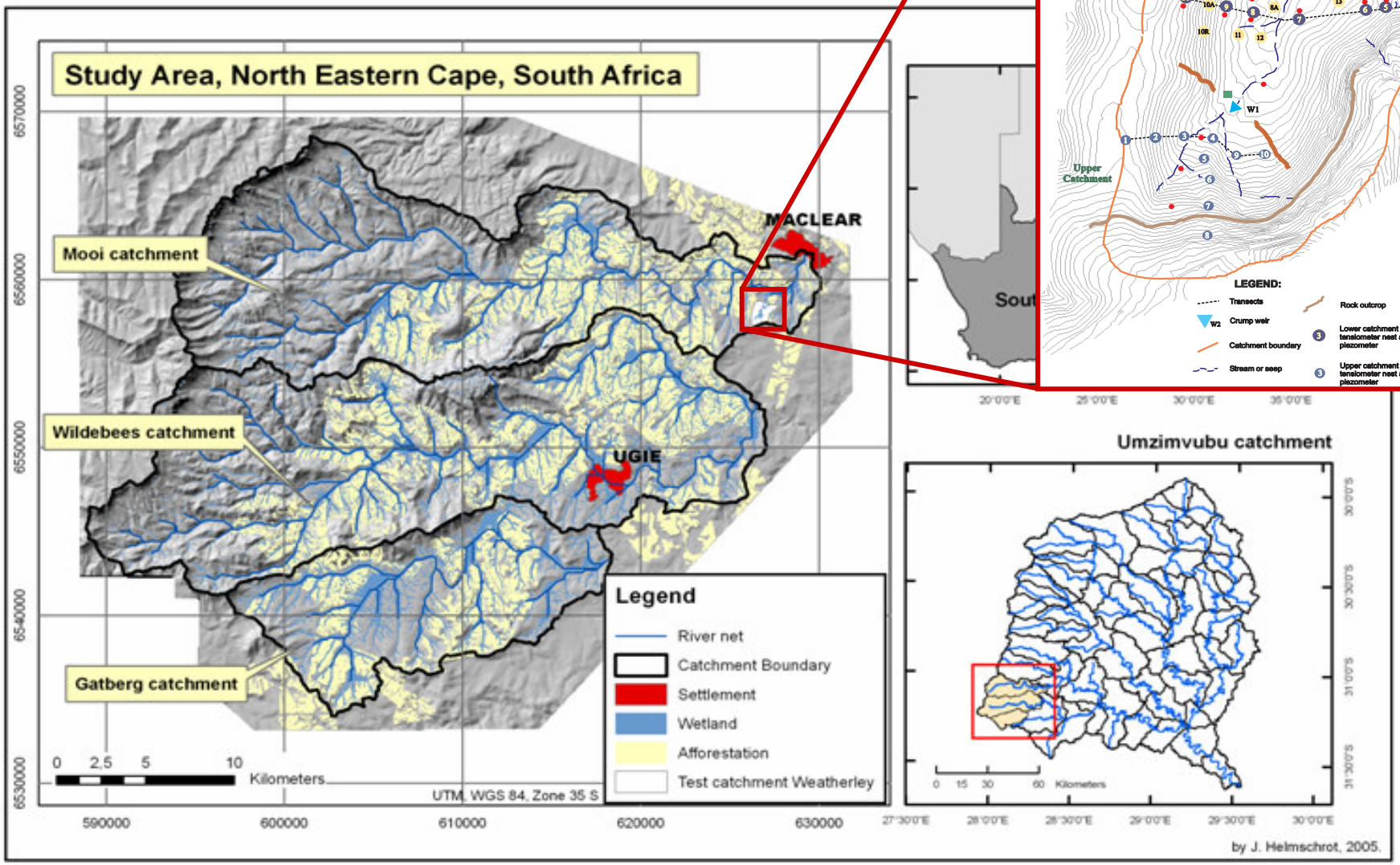
Integrated approaches are a prerequisite to ***understand*** and ***assess wetland functioning*** within a **landscape perspective.**

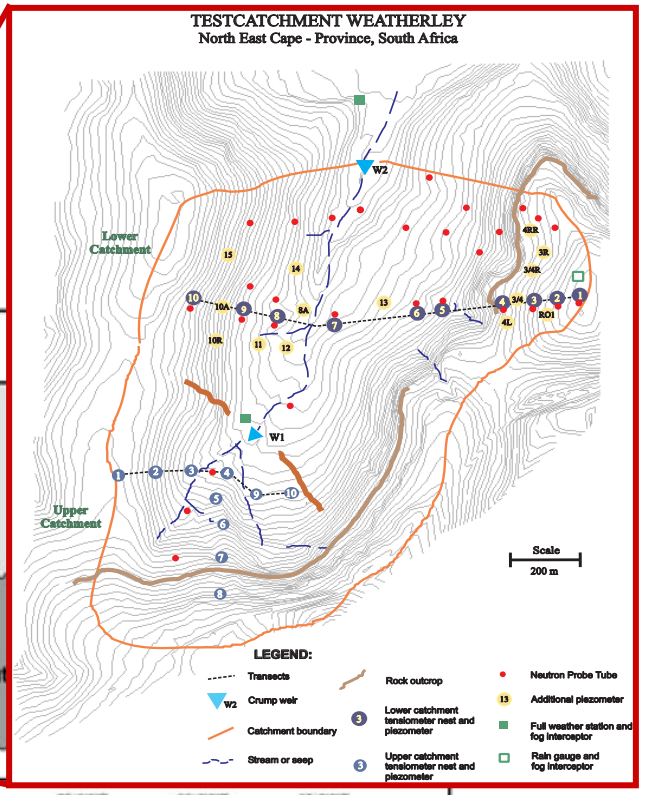
Nested Catchment Approach

Umzimvubu: 20000km²

Mooi: 306 km²

Weatherley: 1.2 km²

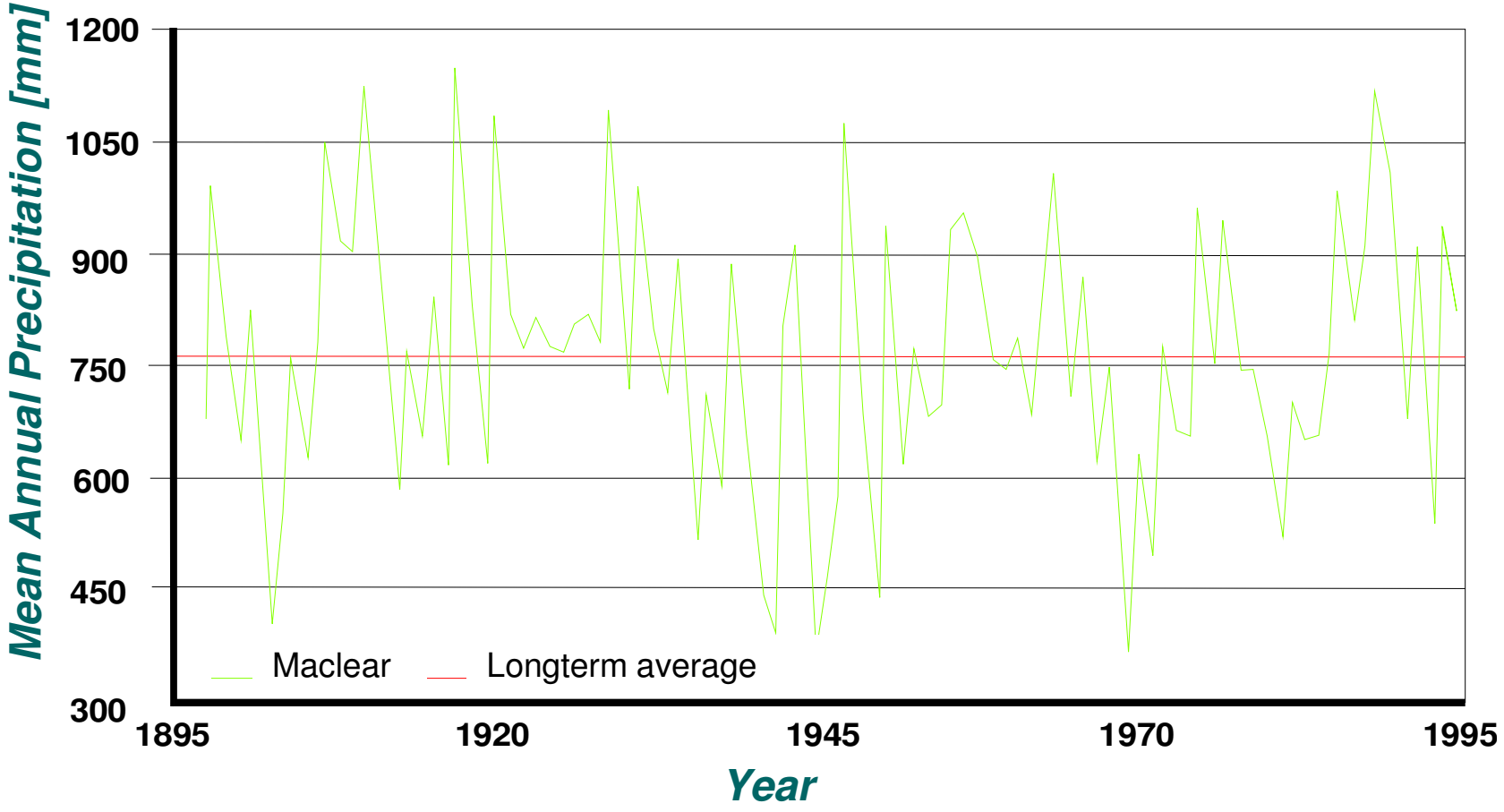




STUDY AREA

Climat

semi-arid conditions, high temporal and spatial variability of rainfall, summer rainfall area, MAP: 750mm, MAT: 15,6 °C



Climat

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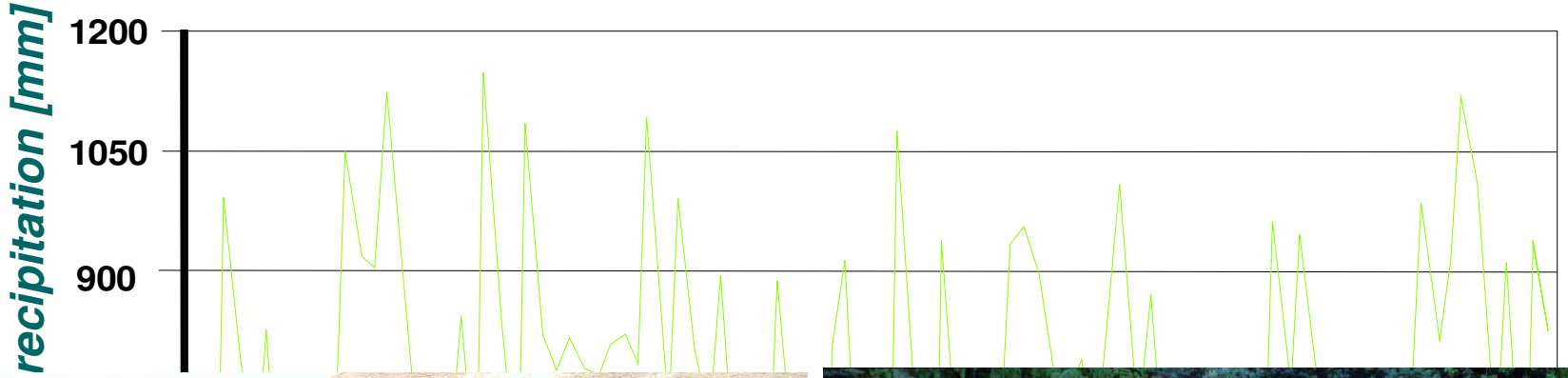


Geology

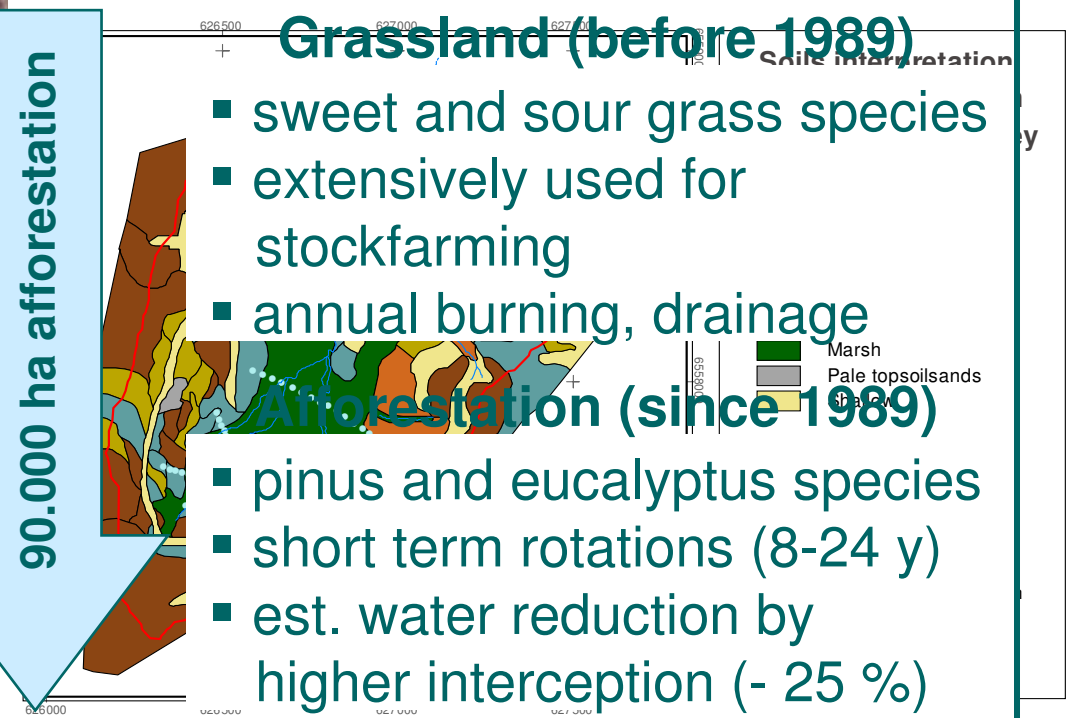
triassic sediments of the Karroo Sequence, mainly changing layers of sand- and mudstone, dolerite dykes

Soils

high variability due to parent material, relief and local climate

Landuse

90.000 ha afforestation



Grassland (before 1989)

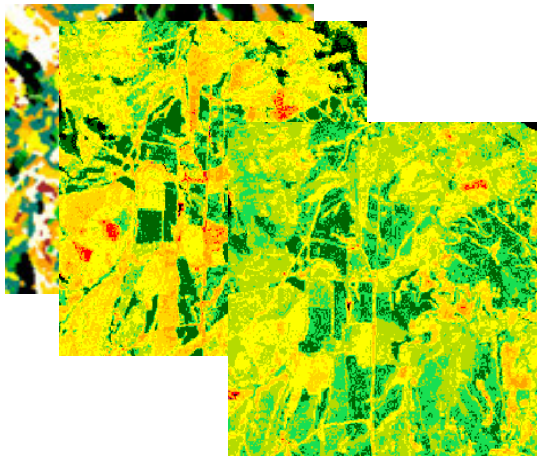
- sweet and sour grass species
- extensively used for stockfarming
- annual burning, drainage

Afforestation (since 1989)

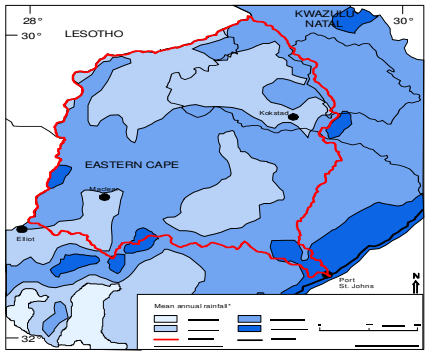
- pinus and eucalyptus species
- short term rotations (8-24 y)
- est. water reduction by higher interception (- 25 %)

Intensive research has been done on several scales (since 1997)

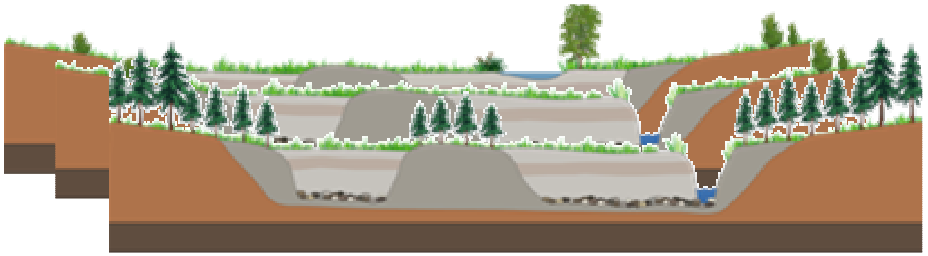
- **Land use change analysis** utilizing Landsat TM/ETM, forestry data, ECDB, field mapping between 1989-2002, ***wetland loss*** since 1989: ca.17% (Helmschrot 2000, 2002)



- **Rainfall dynamics** by analysis of rainfall data of 55 stations from 1970-2003 (Bäse & Helmschrot 2003)

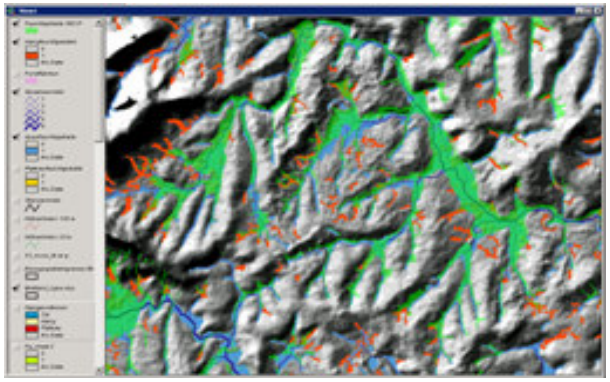


- **Landscape dynamics** using geophysical and sedimentological methods (Hilbich & Helmschrot 2005)

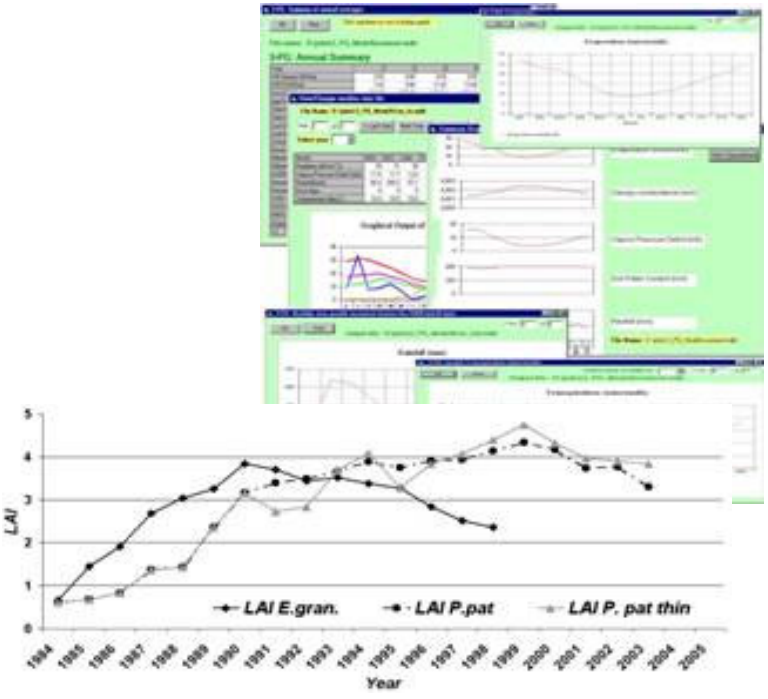


Intensive research has been done on several scales (since 1997)

- GIS-based **relief analysis** by processing DEMs to develop wetland distribution and needed model parameters (Dahlke & Helmschrot 2004)

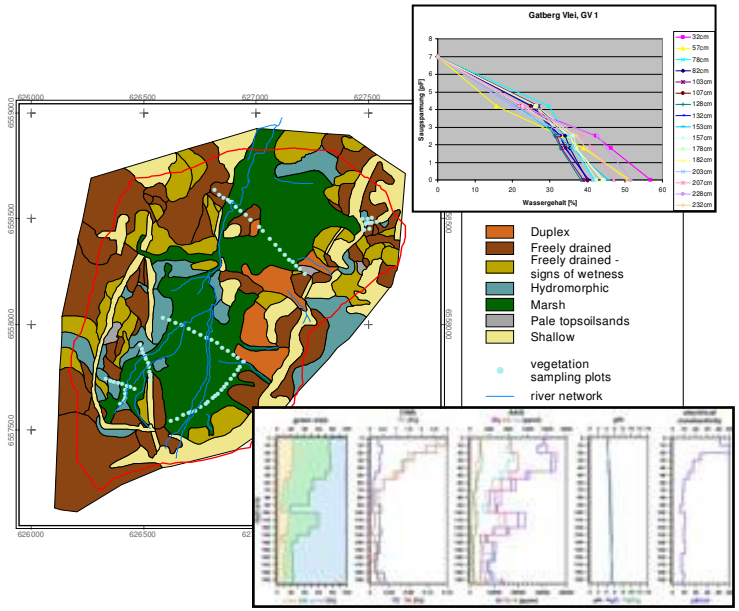


- **Plant growth modeling** for pine/ eucalyptus plantation using 3PG-model (Landsberg & Waring, 1997) and GGLawn (Gruszszynski 2004) for grassland areas (Helmschrot 2001, 2004)

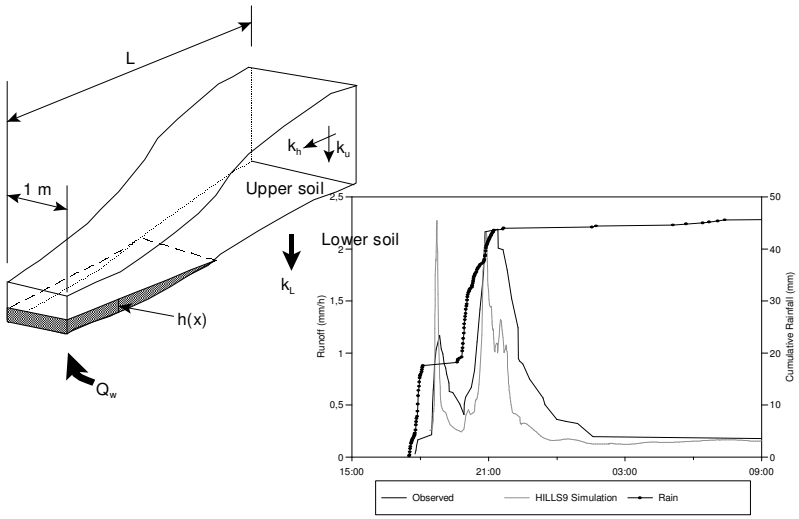


Intensive research has been done on several scales (since 1997)

- **Soil mapping and analysis** to provide distribution and soil para-meters such as grain size, pH, hydraulic conductivity, pF, etc. (ISCW 1999, Lorentz & Helmschrot 2000)

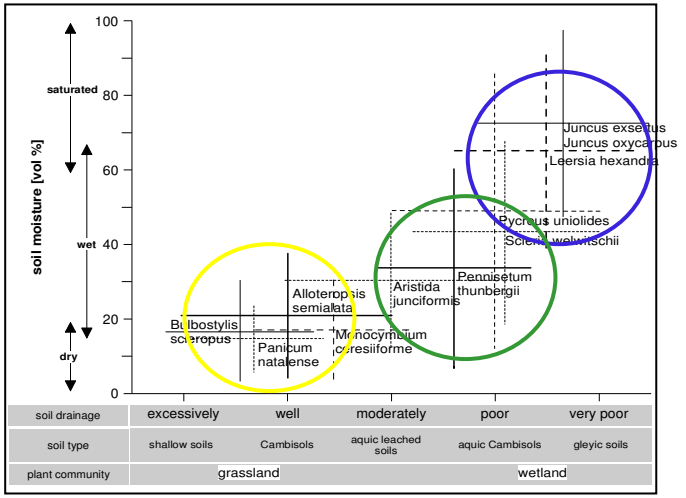


- **Hillslope process studies** to identify, characterize and quantify event-based dynamics of water fluxes on slopes and within valley cross profiles using HILLS9 and HYDRUS2D (Lorentz 2002)

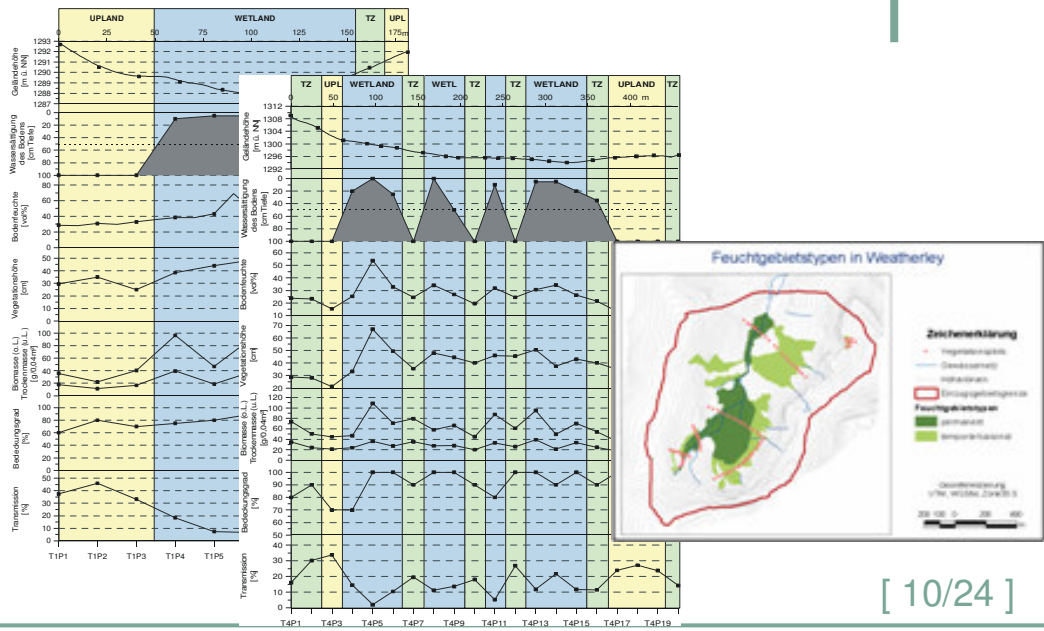


Intensive research has been done on several scales (since 1997)

- **Vegetation studies** in wetland /non-wetland areas to provide vegetation distribution patterns and model parameters (Dahlke & Helmschrot 2003, Helmschrot 2004)



- **Wetland characterization and classification** by combination of intensive field work in selected reference wetlands,results of the base studies and several classifi-cation approaches (Helmschrot 2004)



WET CLASS

Type	Subtypes	WA [ha]	RD [cm]	Soils	Vegetation	Hydro-dynamics	MainSource
Valley Bottom Wetland	floodplain	> 10	45-210	Gleysols	Sedges, hydrophyte grass species	permanent, seasonal	**GW**, **IF**, RF, **retF**
	channel	< 10	30-140	Gleysols, gleyic Planosols	hydrophyte grass species	seasonal	RF, **retF**
	Description: The floodplain wetland type comprises large wetlands in broad valleys controlled by groundwater dynamics and partially associated with interflow and rainfall. They show a high retention potential. Rarely these types are characterized by complex groundwater systems. The channel types are small in extent and mainly controlled by return flow and interflow.						
Slope Wetland	Surface inlet/outlet	> 50	45 - 180	Stagnic Luvisols, Stagnic Cambisols	Sedges, hydrophyte grass species	seasonal, temporal	**IF**, GW, RF
	Only Surface outlet	10-50	40 - 125	Stagnic Luvisols, Stagnic Cambisols	hydrophyte grass species	seasonal, temporal	**RF**, **IF**, retF
	No surface inlet/outlet	< 10	25-125	Stagnic Luvisols, Stagnic Cambisols	hydrophyte grass species	temporal	**RF**
	Description: Slope wetlands are medium-sized wetlands located at downslope areas and mainly controlled by rapid lateral water flow (surface runoff and/or interflow). They are characterized by permeable soil layers with high infiltration capacity.						
Plateau Wetland		< 5	10-50	Stagnic Luvisols, Stagnic Cambisols, Regosols	hydrophyte grass species	temporal	**pGW**, RF
	Description: Small wetland patches in plateau situations, which are associated with perched groundwater and/or precipitation input.						

WA..Wetland area RD..Root Depth GW..Groundwater IF..Interflow RF..Rainfall pGW..perched Groundwater retF..Return Flow

WET CLASS

Type	Subtypes	WA [ha]	RD [cm]	
Valley Bottom Wetland	floodplain	> 10	45-210	
	channel	< 10	30-140	
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Slope Wetland	Surface inlet/outlet	> 50	45 - 180	
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	No surface inlet/outlet	< 10	25-125	
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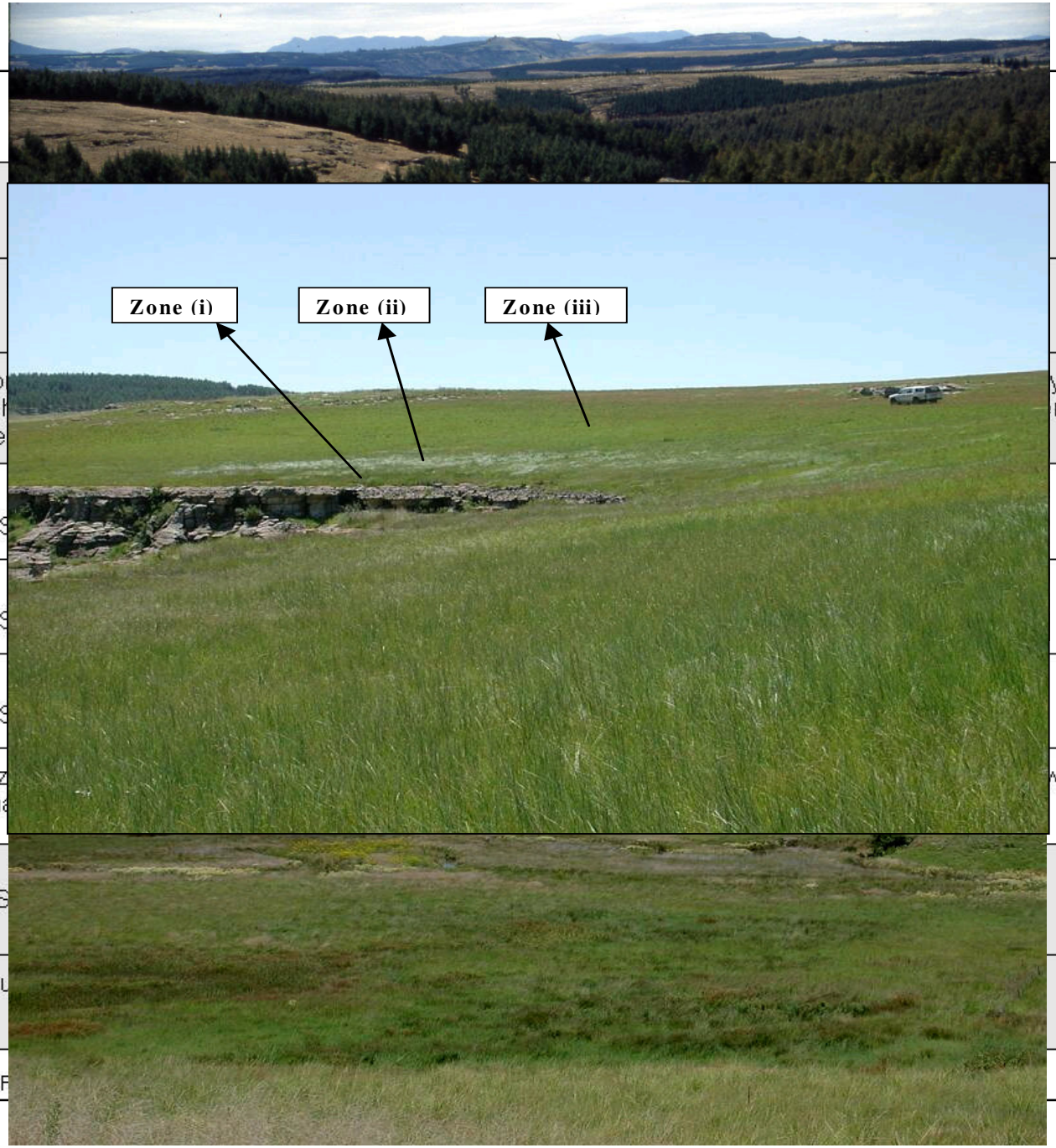
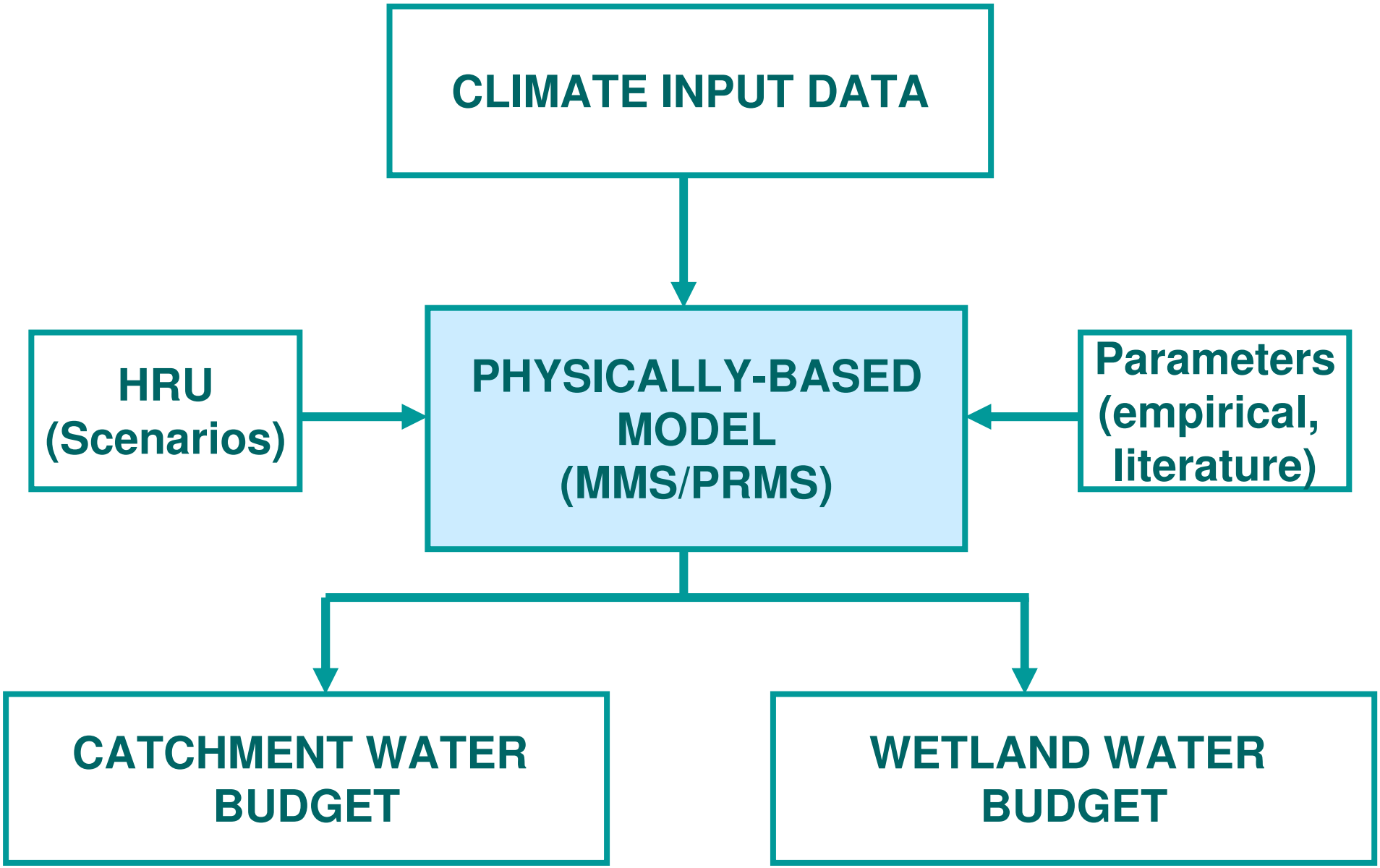
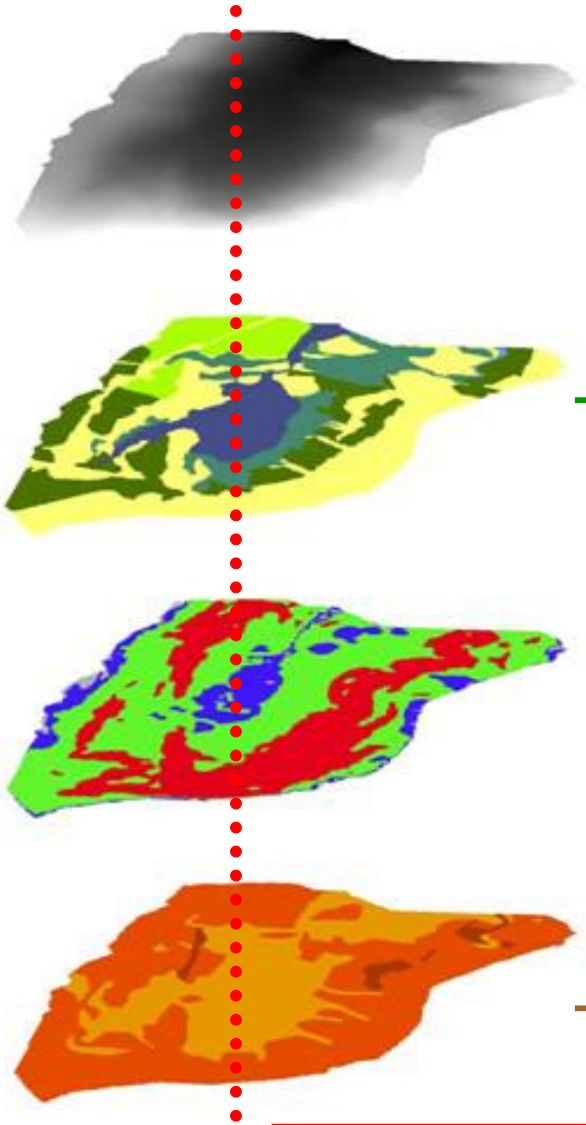
Plateau Wetland		< 5	10-50	
	Description: Small wetland patches in plateau			

WA..Wetland area RD..Root Depth GW..Groundwater IF




CLIMATE INPUT DATA
HRU (Scenarios)
PHYSICALLY-BASED MODEL (MMS/PRMS)
Parameters (empirical, literature)
CATCHMENT WATER BUDGET
WETLAND WATER BUDGET

GIS – Process Level RU – Model Parameter



DEM

Land use

Soil

Geology

GIS Analysis

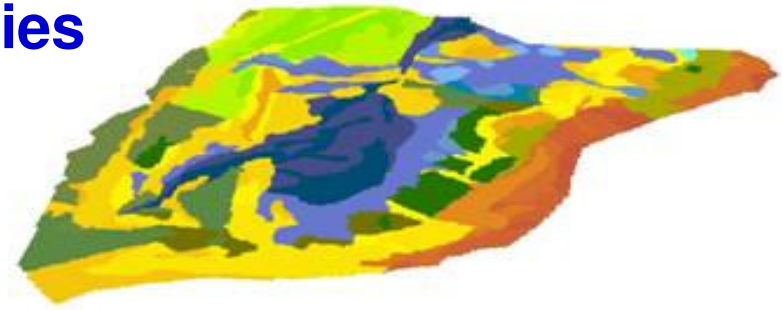
shape, slope, aspect, length, area, topology, relief types, river network

vegetation, aET, sealed area, LAI, roots, interception, wetlands

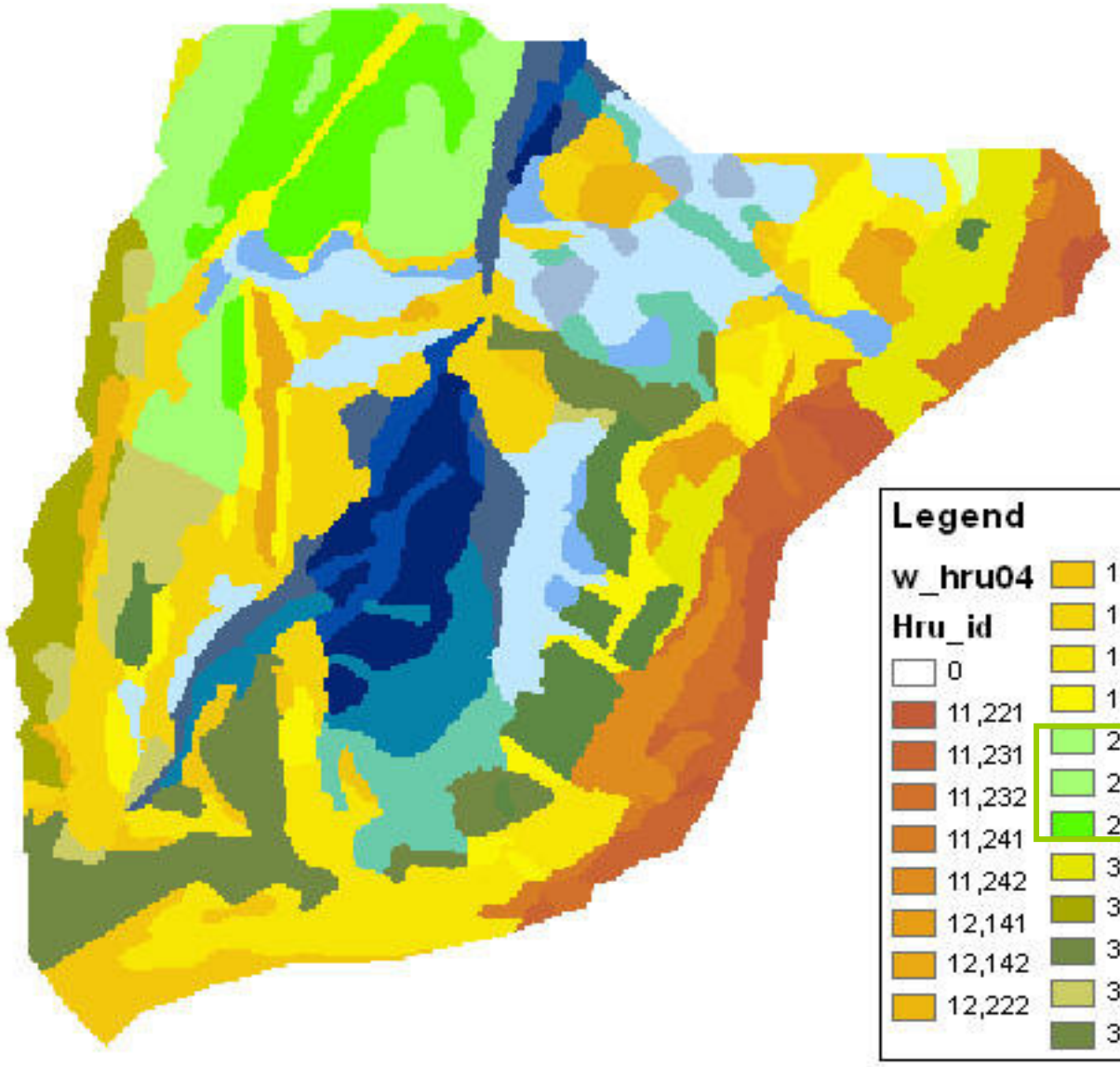
pore volume, field capacity, texture, unsat. conductivity

storage capacity, texture, Darcy-coefficent, sink

HRUs as homogeneous process-related model entities



Weatherley 31 HRUs 2005



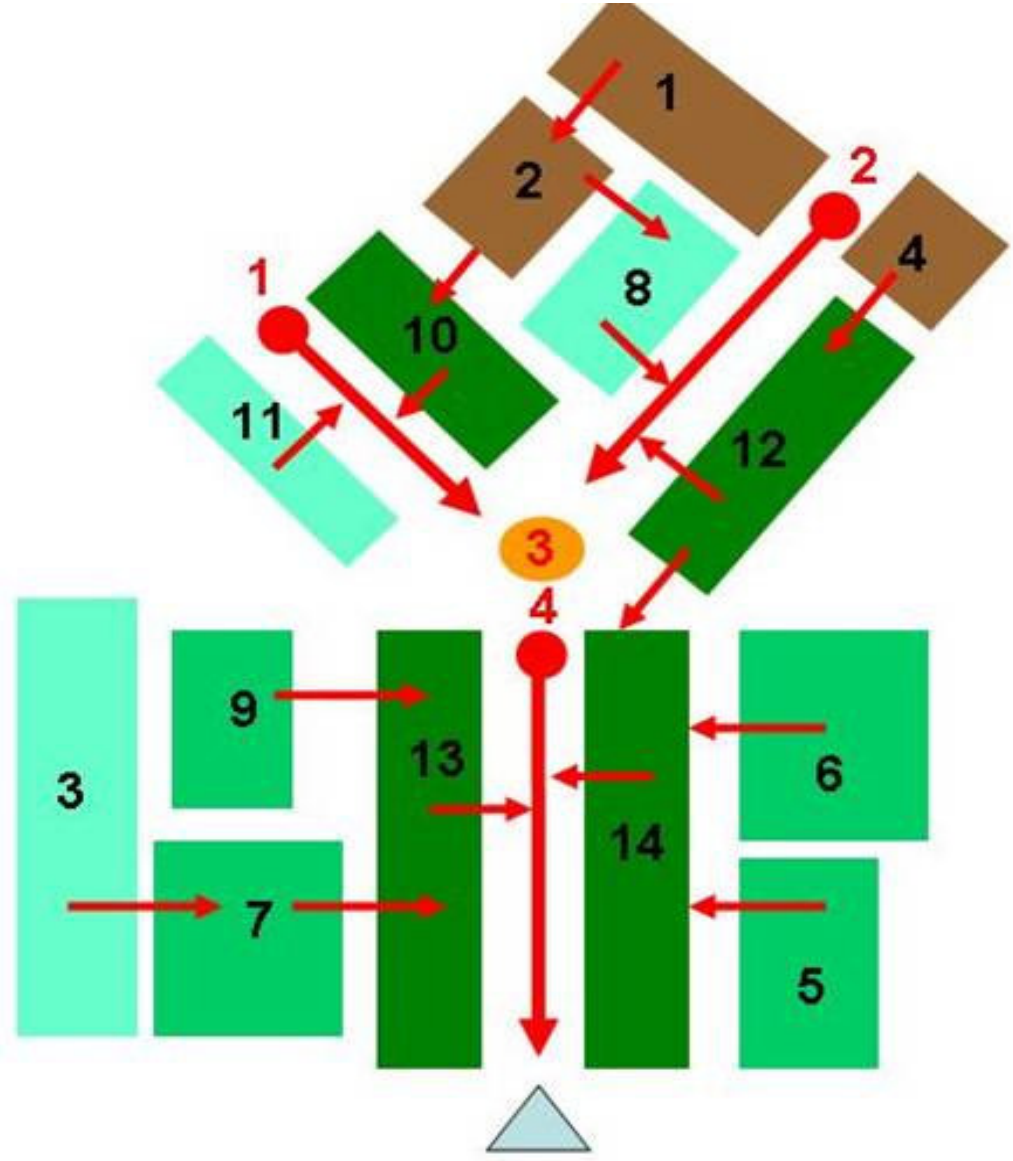
Wetlands (VBW)

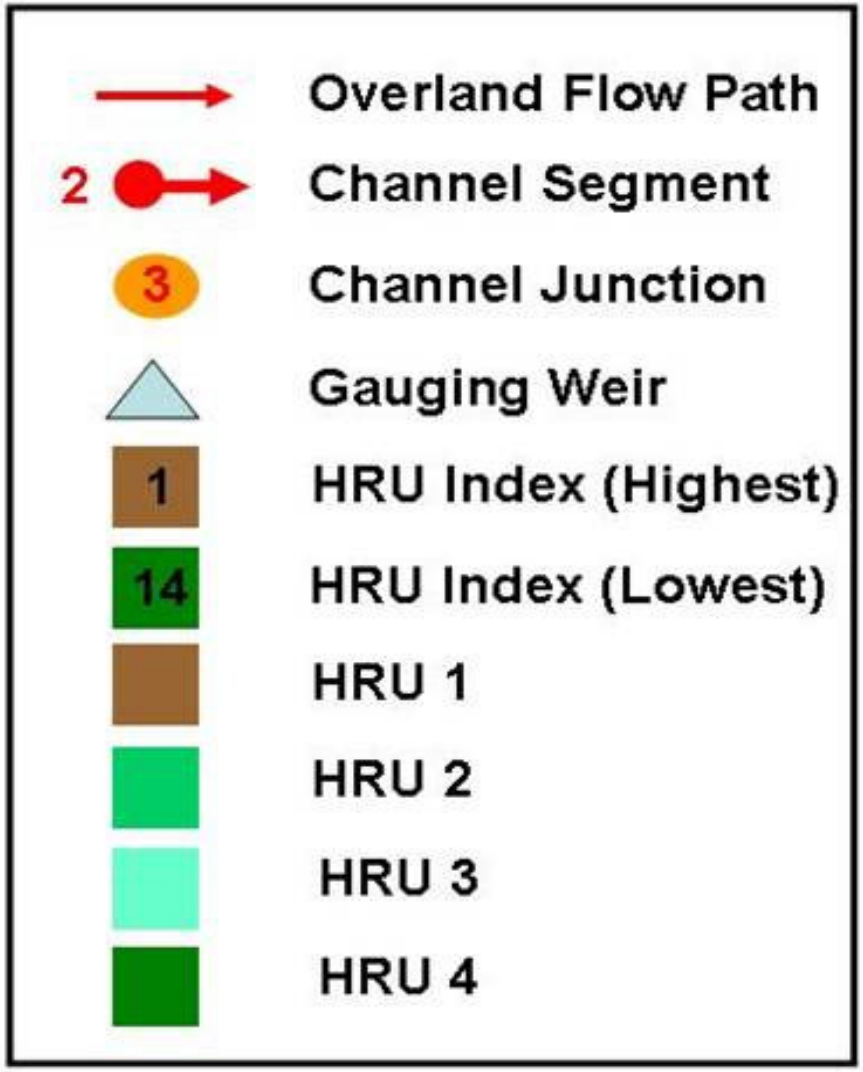
4..wetland
2..valley
3.. clay
2.. slope 0-5%
1..aspect N

Bare rock/soil

Eucalyptus

Topological HRU-ROUTING (n→1)

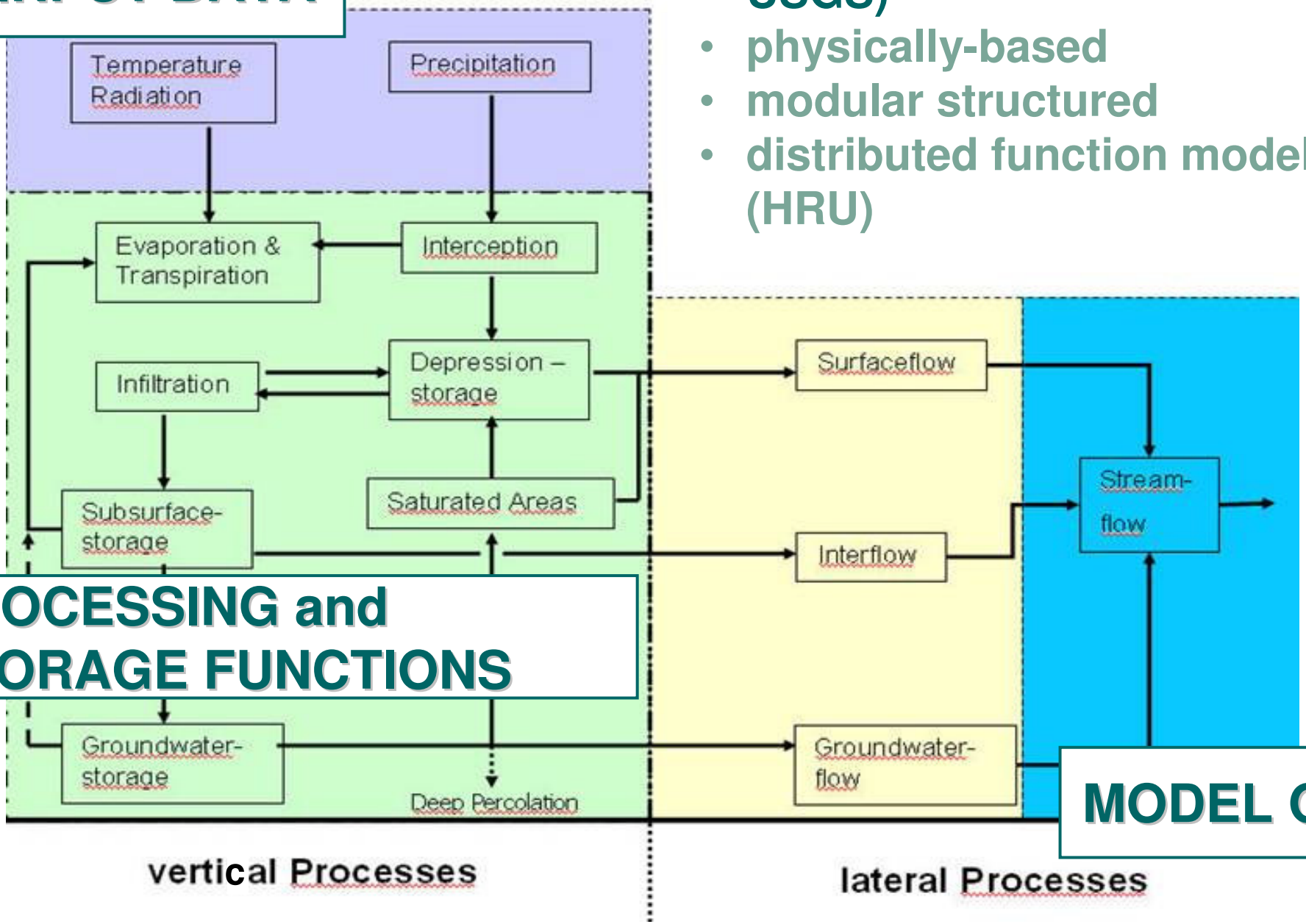




INPUT DATA

MMS/PRMS (Leavesley, 1982, USGS)

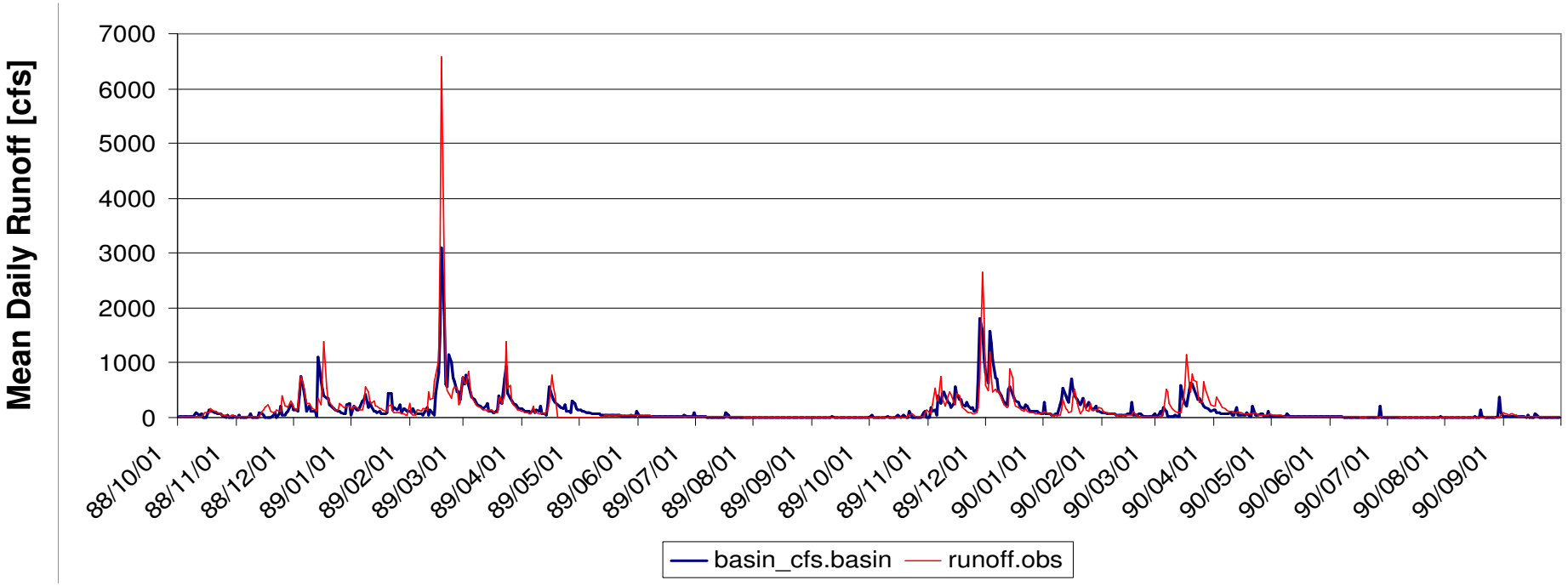
- physically-based
- modular structured
- distributed function model (HRU)



PROCESSING and STORAGE FUNCTIONS

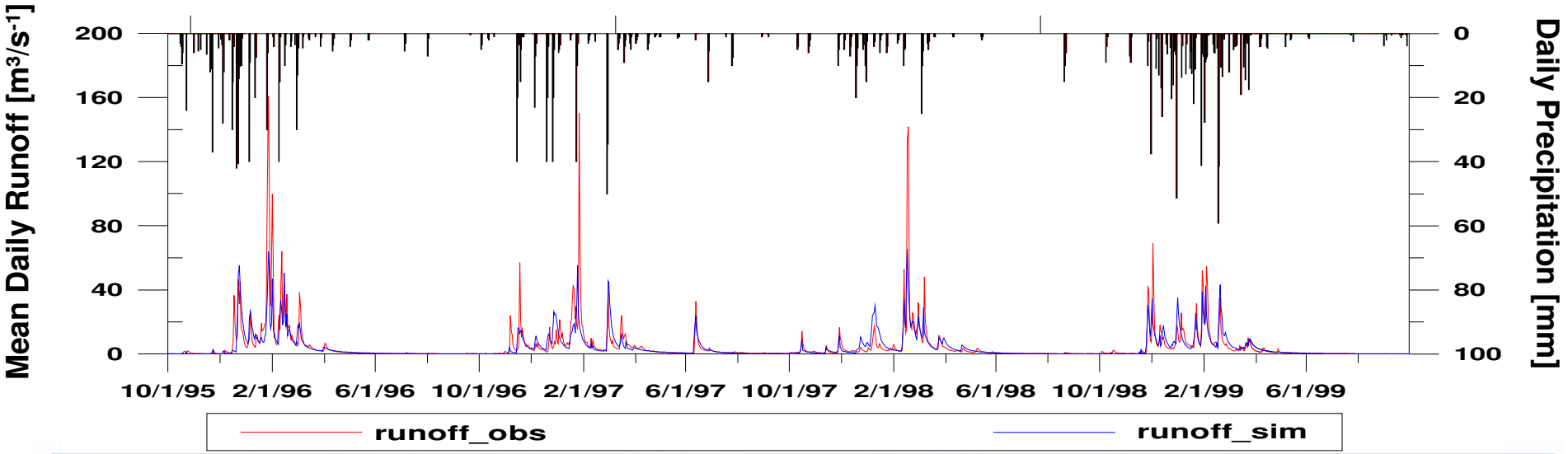
MODEL OUTPUT

Mooi Catchment (305 km²) – grassland
1.10.1988 - 30.09.1990



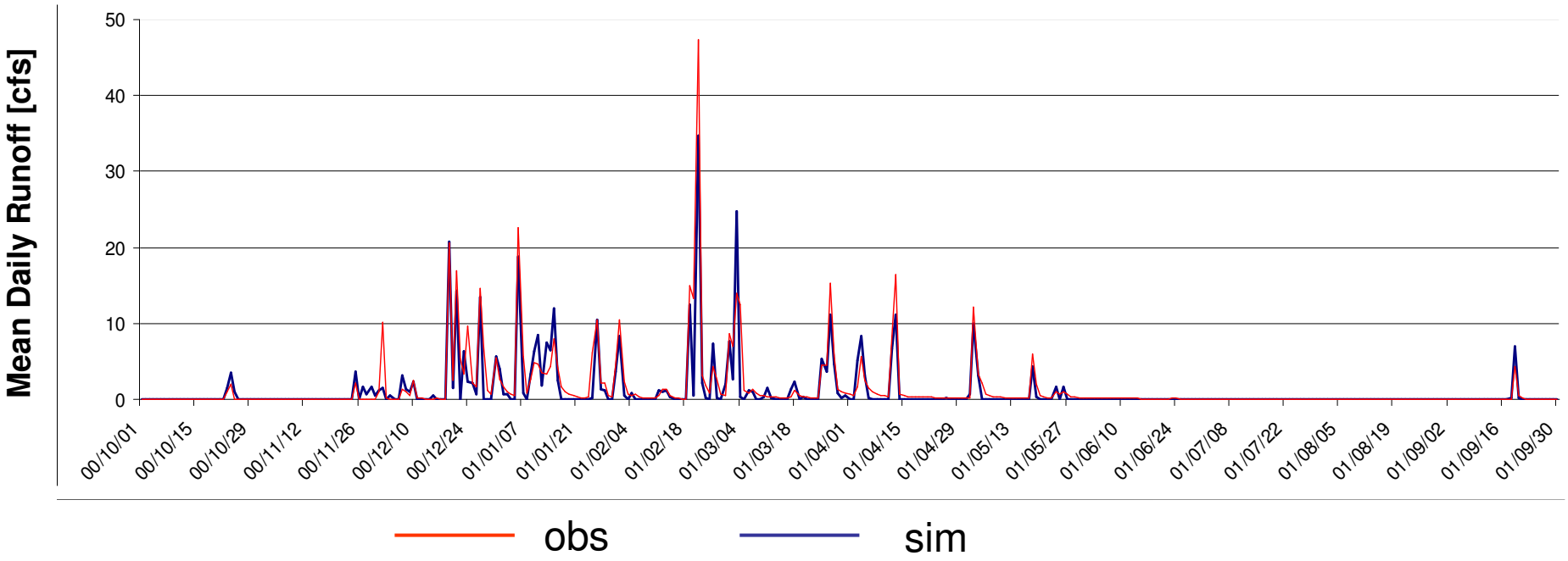
Year	Prec [inch]	ET [inch]	Storage [inch]	P-Runoff [inch]	O-Runoff [inch]	r	r (rain)	r (dry)
1988	2.7	2.48	1.18	0.65	0.69	0.98	0.98	-
1989	32.6	14.52	1.20	16.58	18.34	0.90	0.74	0.95
1990	35.4	18.97	1.73	14.32	14.93	0.94	0.84	0.99
1991	22.9	15.53	1.78	6.88	5.73	0.78	0.67	0.87
1992	33.8	17.69	1.58	14.665	7.55	0.49	0.33	0.94
1993	26.0	16.37	2.87	7.80	3.32	0.69	0.43	0.70

Mooi Catchment (305 km²) – with plantations
1.1.1995 - 22.1.2002



Year	Prec [inch]	ET [inch]	Storage [inch]	P-Runoff [inch]	O-Runoff [inch]	r	r (rain)	r (dry)
1995	17.22	12.40	2.07	3.36	8.12	0.72	0.72	-
1996	39.92	19.83	2.54	16.21	23.43	0.77	0.74	0.95
1997	43.27	21.04	3.74	16.25	20.29	0.89	0.84	0.99
1998	40.27	20.78	3.11	16.34	16.02	0.91	0.67	0.87
1999	38.17	19.56	1.83	16.40	16.75	0.87	0.33	0.94
2000	51.91	20.61	4.06	23.79	27.19	0.81	0.63	0.80
2001	32.56	19.72	3.33	10.224	13.27	0.27	0.31	0.70

Weatherley Catchment (1.2 km²) – grassland
1.10.2000 - 30.09.2001



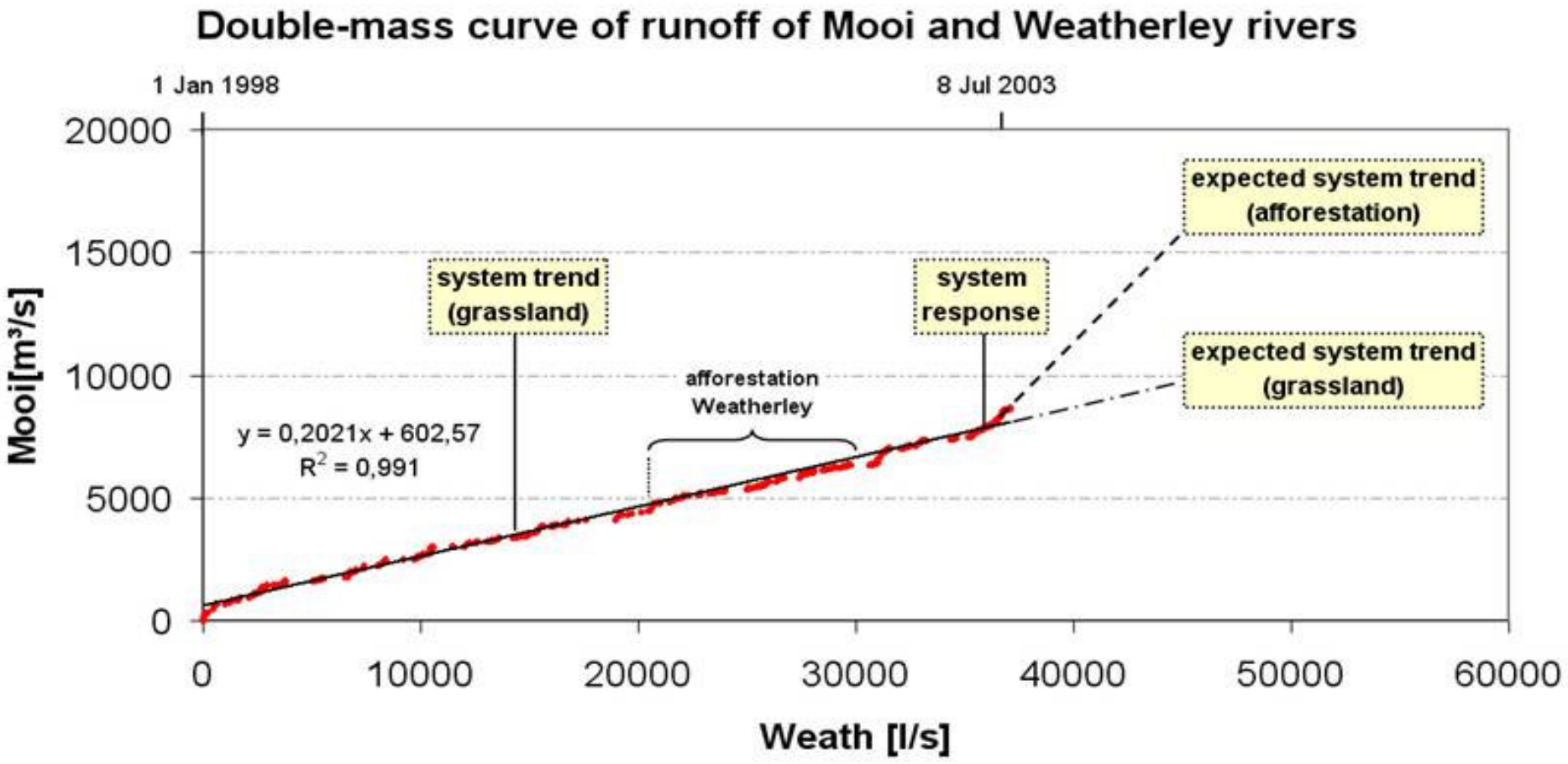
Year	Prec [inch]	ET [inch]	Storage [inch]	P-Runoff [inch]	O-Runoff [inch]	r	r (rain)	r (dry)
1998	26.7	19.89	1.02	6.44	6.6	0.81	0.81	-
1999	40.5	23.53	0.55	17.40	19.0	0.87	0.84	0.87
2000	55.0	22.17	1.27	32.16	33.35	0.94	0.87	0.99
2001	38.9	26.82	1.30	12.02	17.2	0.61	0.31	0.82

Weatherley Catchment (1.2 km²) – with pine/eucalypte 1.10.1999 - 30.09.2001

Results:

- available water will be ***reduced by forest plantations*** by amounts ranging from 10.6% to 21.5%
- this reduction occurs as a result of ***higher interception and evapotranspiration rates*** afforded by the afforestation.
- ***subsurface flow (SSF)*** will be noticeably more affected then ***surface (SF)*** and ***groundwater flow (GWF),*** because of trees are usually planted on hillslopes and available soil water on the slopes will be taken up by the trees instead of generating interflow.
- Since surface runoff is mainly generated on bare soil/rock areas and on grassland during intense rainfalls the SF is less affected than on afforested grasslands.

Wetland-specific changes of water availability in Weatherley (prel.)



stream.

The study has shown that

- MMS/PRMS has been successfully applied to analyse and quantify the temporal and spatial impact of large scale afforestation on different wetland types within a basin.
- forest plantation will reduce available water as a consequence of higher interception considerably.
- the net loss of water due to increased evapotranspiration varies with type and size of wetlands as well as the type of water flow component.
- Additionally the modeling indicates that the wetland water loss is strongly influenced by the surrounding area (planted species).

ACKNOWLEDGMENTS

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- VW-Association (Germany)
- National Research Foundation (South Africa)
- Mondi Forests Ltd. (South Africa)

CONTACT

Thank you very much for your attention!

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